NOTE

This Microfiche meets the quality requirements of the American National Standard for Microfiche of Documents (ANSI PH5.9-1975). However, because of imperfections in the document from which it was made, it contains images that are illegible or difficult to read. The source document for this microfiche is the best copy that could be obtained prior to filming.

CIS

Congressional Information Service, Inc.
Washington, D.C.

Technology, Public Policy, and the Changing Structure of American Agriculture

Volume II—Background Papers

Part A: The Emerging Technologies (Second Section)

16. Land Management
17. Soil Erosion, Productivity, and Tillage
18. Multiple Cropping
19. Present Status and Future Needs in Weed Control
20. Chemical Fertilizers
21. Organic Farming
22. Communication and Information Management
23. Monitoring and Control—Animal Agriculture
24. Monitoring and Control—Plant Agriculture
25. Telecommunication
26. Labor Saving Technology
27. Engine and Fuels
28. Crop Separation, Cleaning, and Processing

May 1986

These Contractor Documents were prepared by outside contractors as an input to an ongoing OTA assessment. They do not necessarily reflect the analytical findings of OTA, the Advisory Panel, or the Technology Assessment Board.

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D.C. 20510

J952-55

Technology, Public Policy, and the Changing Structure of American Agriculture
Volume II--Background Papers

Part A: The Emerging Technologies (Second Section)

Paper No.

16. Land Management by Battelle Columbus Laboratoies
17. Soil Erosion, Productivity, and Tillage by George R. Foster
18. Multiple Cropping by Charles A. Francis
19. Present Status and Future Needs in Weed Control by C.G. McWhorter, W.C. Shaw, and E.E. Schweizer
20. Chemical Fertilizers by Charles H. Davis
21. Organic Farming by William Liebhardt
22. Communication and Information Management by Battelle Columbus Laboratories
23. Monitoring and Control--Animal Agriculture by Battelle Columbus Laboratories
24. Monitoring and Control--Plant Agriculture by Battelle Columbus Laboratories
25. Telecommunication by Battelle Columbus Laboratories
26. Labor Saving Technology by Battelle Columbus Laboratories
27. Engine and Fuels by Battelle Columbus Laboratories
28. Crop Separation, Cleaning, and Processing by Battelle Columbus Laboratories

Background Paper No. 16

Land Management

Battelle Columbus Laboratories
Columbus, Ohio

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

LAND MANAGEMENT TECHNOLOGIES

Summary

Various land management technologies are under development in response to needs to reduce soil erosion, reduce leaching of plant nutrients and chemicals, and reduce fuel costs, while maintaining or increasing crop yields. This paper discusses several lines of research including the following:

- Conservation tillage--a tillage and planting system that leaves at least 30 percent of the crop residue on top of the soil surface after planting;

- Controlled traffic farming--a crop production system in which the crop zone and the traffic lanes are distinctly and permanently separated;

- Customed prescribed tillage--an advanced tillage system in which specifications for crop production, such as requirements for the seed bed, the root zone, pest control, and soil and water conservation are considered;

- Multi-cropping--the practice of planting more than one crop in a field during the same year;

- Organic farming--a farming method where the use of chemical fertilizers and pesticides, along with some mechanical inputs, is either reduced or eliminated.

Many different systems of conservation tillage are being developed in the United States. The specific system used in a particular area depends on the local crops, soil type, moisture levels, and pest infestation, among other variables. Most conservation tillage methods eliminate use of the moldboard plow, employing chisel plows or heavy disks in conjunction with heavy duty planting equipment to cut through soil residues.

Controlled traffic farming currently is a research concept, and not practiced commercially in the United States. The main reason for using controlled traffic farming is to reduce the amount of soil compaction resulting from large, heavy machinery making several passes over the field.

Custom prescribed tillage (CPT) is also in the research stage of development. CPT utilizes information on soil dynamics, machinery, climate, and crop production economics to prescribe the uses of various components for the tillage system. Specific tillage machines to be used are defined, as well as the sequence and timing of their use.

Multiple cropping includes various concepts. For example, strip intercropping refers to growing two crops such as corn and soybeans, together in the same field in strips. In some areas this practice has reduced soil erosion and also increased total crop income. Double cropping is another variation of multiple cropping where a second crop is planted immediately after the first crop is harvested. Double cropping winter wheat and soybeans is common in the southern United States.

Organic farming methods may be attractive to some new entrants in agriculture who lack funds for getting started, since organic farming uses fewer purchased inputs such as fertilizers, chemicals, and machinery.

There are no particularly unique or new machinery requirements needed to further implement conservation tillage, multi-cropping systems, and organic farming. However, in order to commercialize controlled traffic farming and custom prescribed tillage, considerable interdisciplinary research involving agronomists, horticulturists, agricultural engineers, crop physiologists, and agricultural economists is required. These concepts have many perceived economic benefits; however, the true cost/benefit relationships remain to be investigated for the wide variety of crops, terrain, soil types, precipitation, and temperature conditions existing across the United States. The engineering and mechanization technologies are not insurmountable, but it is important to determine the effects of controlled traffic farming and custom prescribed tillage on the farmer's net profit per acre before widespread adoption can be expected. One major obstacle to adoption of custom prescribed tillage is that there is currently no bank of information containing the "prescriptions" for specific crops or varieties, soil types, and soil and environmental conditions.

Increasing national concern over soil erosion and the consequent long-term effects on soil productivity will spur development of improved land management practices. The degree of soil erosion and its effect on soil productivity varies widely across the United States. The quality of the subsoil in terms of water holding capacity, pH, and nutritional content is an important factor affecting crop productivity where erosion occurs.

While organic farming may be desirable for certain locations and certain individual farmers, it is not expected to be adopted on a wide scale in the United States in the foreseeable future. Widespread adoption of organic farming would likely reduce crop yields, reduce the quantity of crops available for export, and increase retail food prices.

LAND MANAGEMENT TECHNOLOGIES

Introduction

The land is one agricultural resource that cannot be replaced. In the future, new methods of land management will be developed that will conserve more soil while increasing yields. It is expected that the major lines of research in this area will include:

- Conservation tillage
- Controlled traffic farming
- Custom prescribed tillage (CPT)
- Multi-cropping systems
- Organic farming.

Conservation tillage is a tillage and planting system that leaves at least 30 percent of the crop residue on top of the soil surface after planting. Any system that meets this requirement, including no-till, slot planting, strip-till, mulch-till and reduced-till, is a conservation tillage system. Conservation tillage systems are being adopted across the country, primarily to conserve soil and decrease tillage and energy costs.

Controlled traffic farming is a crop production system in which the crop zone and the traffic lanes are distinctly and permanently separated.

The main reason for using this method is to reduce the amount of soil compaction that results from large, heavy machinery making several passes over the field. Many scientists consider soil compaction from this traffic to be a major problem with serious long-term ramifications for increased soil erosion and reduced crop yields. Another important reason for the use of this system is to maximize traction performance.

Custom prescribed tillage (CPT) is a term coined by the tillage engineering group at Auburn University to describe a type of advanced tillage system. In this system's approach to tillage, specifications for crop production, such as the requirements for the seed bed, the root zone, pest control, and for soil and water conservation will be considered. The next step is to use the available information on soil dynamics, machinery, economics and climate to prescribe components of the tillage system and how they should be used. The specific machines to be used will be defined, as well as the sequence and timing of their use.

With this system only the appropriate amount and type of tillage will be used. CPT could decrease tillage costs per acre, while providing higher quality and quantity of products. Conservation tillage is a form of custom prescribed tillage. The CPT method attempts to optimize the output for a prescribed set of inputs. For many farms, reducing the amount of tillage by using conservation tillage systems is an obvious optimization.

Multi-cropping is the practice of planting more than one crop in a field during the same growing season. This definition includes strip inter-cropping (growing crops side-by-side simultaneously) and double-cropping (sequentially following one crop with another during one growing season), among others.

Organic farming is a method of farming where the amounts of chemical and mechanical inputs are reduced or eliminated. The origin of the organic farming movement is traced to Sir Albert Howard in the years prior to World War I. He taught that, except for "natural" products such as phosphate rock and limestone, importation of plant nutrients from off the farm is to be avoided. This judgement about the acceptability of naturally occuring chemicals has now been expanded by many in the organic movement to include the issue of safety. They regard natural chemicals as safe, and chemicals that are artificial, synthesized or processed as hazardous and therefore to be avoided. The organic farming movement is very controversial in the agricultural community. (CAST, Report No. 84, 1980).

Current State of the Art

Conservation Tillage

Many different systems of conservation tillage are used in the U.S. According to one source, the use of conservation tillage has increased at an annual rate exceeding 13 percent since from 1972 to 1982 (Perkins, 1983). The system used depends on the local crops, soil type, moisture state, and pest infestation, among other variables. Manufacturers are marketing lines of equipment that meet the special needs of conservation tillage. For example heavy planters with powered cutting coulters have been developed to plant seeds in soil that has not been prepared with standard tillage systems.

Reduced-till is a method of farming using fewer soil preparation steps and a primary tillage tool other than a moldboard plow. A chisel plow or heavy disk may be used as the primary tillage tool. These implements generally leave more residue on the soil surface than a moldboard plow. The planter may need some modification to operate properly in the heavy plant residue.

Mulch-till uses equipment that loosens and aereates the soil by cutting horizontally several inches below the soil surface. Wide sweeps and blades up to 30 inches in width are used. This practice leaves the residue on the soil surface while also providing a good seed bed.

Strip-till methods prepare the seed bed by sweeping some of the residues away from the seed bed area and tilling only the area that will be used for the seed bed. Since only a small percentage of the total field is tilled energy requirements are decreased. Slot planting or no-till is similiar to strip-till except that in slot planting, a very narrow slot is cut into the undisturbed soil, reducing the energy requirements even more.

Controlled Traffic Farming

Controlled traffic farming currently is currently practiced in the United States to the extent that current machinery systems allow. A large amount of research is underway within ARS/USDA and at several land-grant universities and agricultural experiment stations. Most of this research indicates that substantial benefits can be realized by the use of this practice. Some of these possible benefits include:

- Less fuel for tillage
- Improved tractive efficiency
- Better tire flotation for wet harvest
- Improved rate of crop maturity

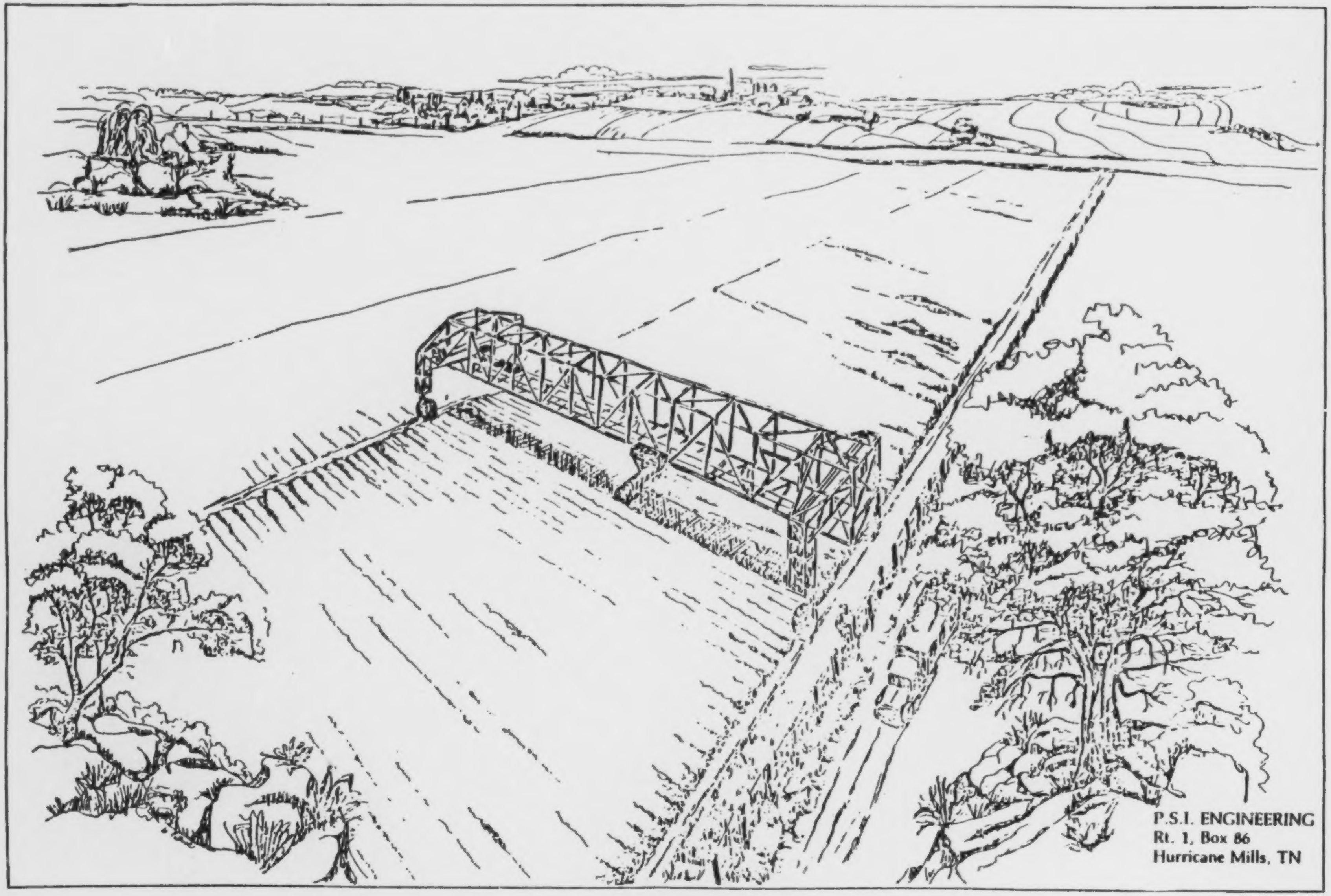
- Decreased pathogenic fungus populations
- Decreased nematode populations
- Improved insect control
- Decreased soil erosion
- Decreased chemical and fertilizer runoff losses
- Improved timeliness of operations.

Much of the current research is attempting to determine the benefits and problems that occur when adopting this technology. Several research institutions have purchased or developed equipment that can be used on test plots to perform controlled traffic research. There are no commercially available machinery systems designed specifically for controlled traffic.

Texas A&M is evaluating a system that may be commercially feasible. It is based on a cable towing system for moving equipment across a field in a controlled path. Another prototype machine has been built in Tennessee by a private company that spans a 100-foot crop area (Figure 1). The builder* estimates that the base machine can be built for $100,000 . Implements are supported from the machine. This system is similar to the crane farming systems being tested in Japan. The Tennessee machine operates on rubber tires and is steered by the operator. The Japanese machine rides on rails. The Texas A&M machine and the Tennessee machine perform all operations perpendicular to the direction of travel of the machine. Several of the machines built by, or for, the USDA and land grant

---

* P.S.I. Engineering, Hurricane Mills, Tennessee



P.S.I. ENGINEERING
Rt. 1, Box 86
Hurricane Mills, TN

FIGURE 1. PRECISION FARMING.

research institutions perform operations parallel to the direction of travel. Because of the power requirements, these machines are much smaller than those described above. Usually, they cannot span more than 40 feet.

Custom Prescribed Tillage (CPT)

Many modern agricultural production systems practice CPT to some extent. The controlled traffic system of row crop production is an example where wheel traffic is confined to special traffic lanes, thus avoiding wheel traffic over seeding and water-management zones. This system of soil structure management recognizes the contrasting needs of a traffic lane and a seedbed and rootbed.

Some tillage research aimed at minimizing tillage operations and field travel (primarily to reduce costs, minimize soil compaction and reduce soil erosion) has prescribed each operation for a specific zone and objective. Although a wide variety of tillage machines is common to many locations, tillage methods and management techniques developed at one location may not be applicable at another. (Johnson, 1981).

The National Tillage Machinery Laboratory, Auburn University and the ARS/USDA Soil and Water Research Unit at Auburn, Alabama, are using the CPT concept to develop a tillage machinery system and the associated conservation farming practices for some soils located in the central to western areas of Alabama. These soils have a very high clay content and because of this characteristic and others, preparation of a high quality seedbed is often very difficult. The prescription for this soil required that seed bed preparation equipment be developed, as well as changes in current cultural practices.

A futuristic depiction of custom prescribed tillage is illustrated in Figure 2.

Multiple Cropping

Economic considerations are forcing farmers to increase and diversify their production given their available resources. One possible approach is to grow two or more crops during the same year. Generally, currently available machinery is used to perform the field operations needed. However, in some cases, modified or new equipment is used. For some of the cropping systems being studied, new equipment must be developed for the cropping system to be feasible.

Strip inter-cropping is a system that Chinese farmers began using 4,000 years ago. It can help prevent soil erosion losses when some of the strips are seeded to a close-growing crop. In addition, when complementary crops are inter-cropped, some research shows that yields can be increased. For corn/soybean inter-cropped fields, corn yields have been increased as much as 30 percent over conventional corn growing systems. This yield increase is attributed to the fact that the corn next to the soybeans receives more sunlight and can extract water and nutrients from a larger amount of soil. The yield from the soybeans can be reduced, especially in dry years. However, the combined crop income in dollars per acre can be higher.

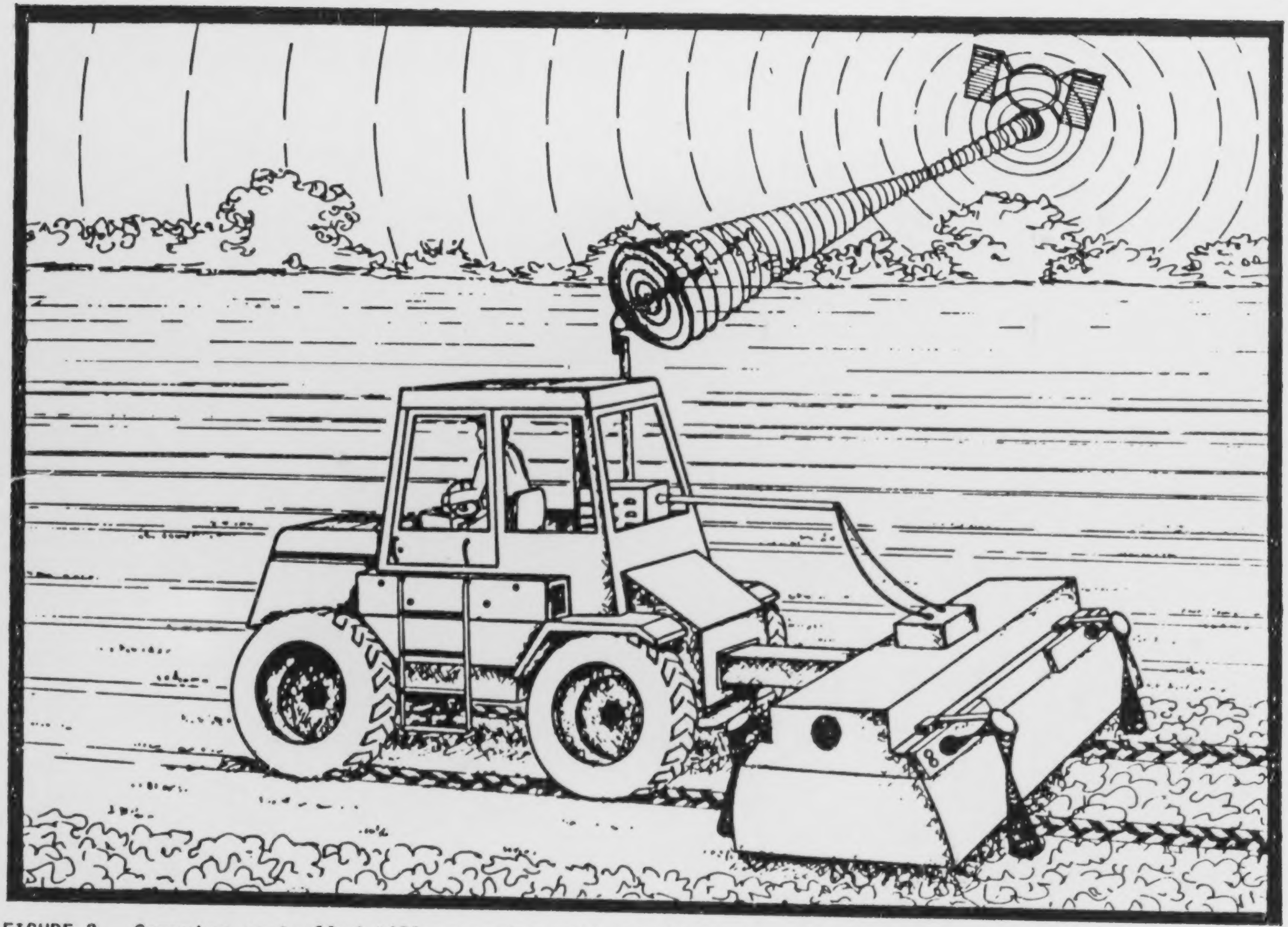


FIGURE 2. Computer-controlled tillage system with satellite communication for achieving custom prescribed tillage. From: National Tillage Machinery Laboratory, U.S. Department of Agriculture; Auburn, Alabama.

Another combination that can be used in intercropping is to plant a legume (e.g., alfalfa) between the rows of a nonleguminous crop (e.g., corn). The legume may supply 50-100 pounds of nitrogen per acre. This amount of nitrogen is inadequate in the Corn Belt. Thus, supplemental nitrogen must be added to a legume-corn intercrop system. Unfortunately, legumes preferentially use supplemental fertilizer nitrogen before fixing atmospheric nitrogen, with the net effect being little, if any, reduction in nitrogen needed.

Double-cropping is the practice of planting a second crop after the harvest of the first crop. For this to be possible, a long growing season must be available. Often, the second crop is planted in the stubble of the first crop, thus decreasing the amount of soil erosion. Double-cropping winter wheat and soybeans is commonly done in the southern states. Currently available machinery and practices are used to perform the field operations needed. Machinery developed for minimum-till or no-till applications is often used.

Organic Farming

Organic farming is not practiced on a large amount of U.S. acreage. Organic farmers often sell their products to markets willing to pay a premium for the assurance that commercial fertilizers and chemical pesticides have not been used during production. Organic farmers generally prefer to use fewer technological inputs than conventional farmers, including lower levels of mechanization. Because commercial fertilizers are not used, organic farmers derive their nitrogen requirements from the planting of leguminous crops in rotation with the nonleguminous crops. A small amount of additional nitrogen is supplied by applying animal manure. Widespread adoption of organic farming would reduce crop yields, as indicated in a subsequent section of this paper.

If adopted on a large scale in the U.S., the need for mechanization technologies would be reduced. One of the few areas that mechanization research would be needed in is the area of waste handling systems for livestock.

Major Breakthroughs Needed

In order to commercialize new land management technologies such as controlled traffic farming and custom prescribed tillage, considerable interdisciplinary research is required. While these concepts have many perceived economic benefits, the true cost/benefit relationships remain to be investigated for the wide variety of agricultural crops, terrain, soil types, precipitation, and temperature conditions that exist across the United States. The major obstacles are not necessarily development of new engineering or mechanization technologies, but rather determining the effects of controlled traffic farming and custom prescribed tillage on the farmers net profit per acre.

For example, Cooper et. al., (1983) identified some problems to be addressed to make controlled traffic farming feasible. These include:

- Develop or modify equipment that could be used in a number of locations throughout the United States for research on crop production systems utilizing controlled traffic;

- Conduct yield studies on certain crops such as alfalfa, potatoes, vegetables, and cotton in the western United States; soybeans, cotton, and corn in the Southeast; corn and soybeans in the North Central states; and vegetables and small fruits in the Northeastern part of the United States

- Measure the effect of controlled traffic cropping systems on water and soil losses, compared to conventional crop systems;

- Compare energy utilization of conventional cropping systems with controlled traffic systems;

- Study the crop protection needs (weed, disease, insect, and nematode control) using several controlled traffic cropping systems;

- Investigate changes in irrigation management under controlled traffic cropping systems compared to conventional cropping systems;

- Determine the most effective row and plant spacing for various crops;

- Determine possible changes in fertilizer application rates and incorporation methods;

- Investigate soil microbiology and rate of organic matter decomposition under various controlled traffic systems;

- Determine the overall economics of developing equipment necessary to commercialize controlled traffic systems, and;

- Determine which systems (for example, systems with spans ranging from 30 feet to 100 feet have been suggested) offer the best overall advantages.

The development and application of custom prescribed tillage (Figure 3) for crop production systems will require specifications for the soil condition desired, instantaneous and continuous measurement of the soil condition (before and after tillage), and precise application of energy to create the desired soil condition. Currently, there is no bank of information containing these "prescriptions" for specific crops or varieties, soil types, and soil and environmental conditions.

A control concept for implementation of custom prescribed tillage systems is illustrated in Figure 4 (Schafer, et al, 1981). For optimum results, the control system must be consistent in its capabilities of sensing, evaluating, controlling, and actuating. In other words, the system must respond to a given control situation in the same manner

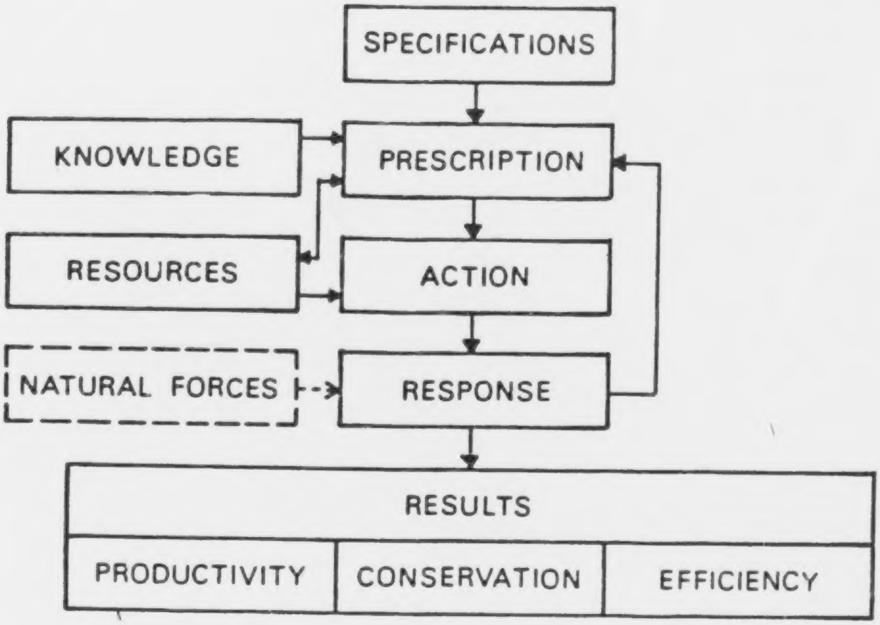

SPECIFICATIONS
KNOWLEDGE
PRESCRIPTION
RESOURCES
ACTION
NATURAL FORCES
RESPONSE
RESULTS
PRODUCTIVITY
CONSERVATION
EFFICIENCY

FIGURE 3. CUSTOM PRESCRIBED TILLAGE (CPT). FROM NATIONAL TILLAGE MACHINERY LABORATORY; AUBURN, ALABAMA.

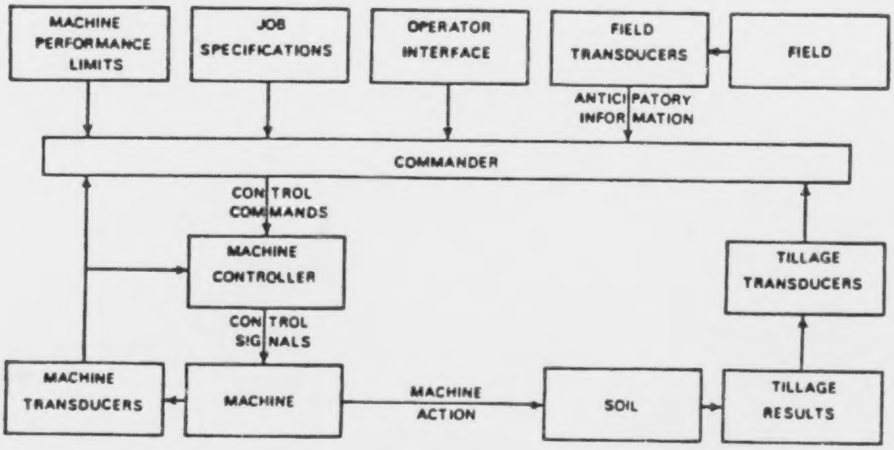

MACHINE PERFORMANCE LIMITS
JOB SPECIFICATIONS
OPERATOR INTERFACE
FIELD TRANSDUCERS
FIELD
ANTICIPATORY INFORMATION
COMMANDER
CONTROL COMMANDS
MACHINE CONTROLLER
TILLAGE TRANSDUCERS
CONTROL SIGNALS
MACHINE TRANSDUCERS
MACHINE
MACHINE ACTION
SOIL
TILLAGE RESULTS

FIGURE 4. A CONTROL CONCEPT FOR TILLAGE SYSTEMS. FROM NATIONAL TILLAGE MACHINERY LABORATORY; AUBURN, ALABAMA.

Source: "Control Concepts for Tillage Systems", Paper No. 81-1601, by R.L. Schafer, S.C. Young, J.G. Hendrick, and C.E. Johnson. American Society of Agricultural Engineers; Chicago, Illinois, December, 1981.

regardless of changes in the peripheral environment. In addition to lack of information on specifications for soil conditions for optimum plant growth, it will be necessary to develop control algorithms for the COMMANDER and MACHINE CONTROLLER shown in Figure 4. Field TRANSDUCERS and TILLAGE TRANSDUCERS must also be developed. Finally, all of the components of the required knowledge must be effectively integrated to develop a new system of custom prescribed tillage.

Multi-cropping systems do not require any mechanical or electronic breakthroughs for their implementation. Multiple cropping patterns may impose design and operational restrictions on the implements used for mechanizing crop production. However, the machinery requirements for growing a crop in multiple cropping patterns are no different than for growing the same crop as a sole crop (Erbach and Lovely, 1976).

When multiple crops are grown on the same land area at the same time, mechanization becomes more complex because the operation performed on, or for, one crop must be done in a manner that will not damage the other crop or crops. For example, strip intercropping corn and soybeans requires different herbicides. Care must be taken so that herbicides used to control broadleaf weeds in corn do not damage the soybeans.

In general, successful double cropping (following one crop with another sequentially within a growing season) requires that machinery be available to quickly harvest and plant. Planting equipment must be free of unnecessary appendages, shanks, chains, and other components that can catch plant residue.

Often plants in a double cropping pattern may have limited moisture supply and a short growing season. Therefore, they are not likely to grow as tall or branch out as much as the same crops grown under conventional conditions. Narrower rows and higher plant populations may aid weed control and increase yields. Therefore, equipment may be needed to plant, cultivate, and harvest narrow rows. However, this equipment has gradually evolved over the past 15-20 years, and should not present any major engineering challenges.

Other general adaptations that will aid multiple cropping mechanization include planting in rows and strips sufficiently wide to allow passage of all equipment, thus eliminating the need for equipment adaptations. Multiple cropping involves a steady cycle of planting and harvesting, therefore, it may be desirable to maintain traffic paths to aid mechanization of the system. This would be an advantage of controlled traffic farming, which would allow for the flexibility and precision required for multiple cropping.

There are no mechanical barriers to organic farming. Many aspects of conservation tillage, which is predicated upon returning crop residues to the soil, apply to organic farming. Obviously, spraying equipment for application of chemical fertilizers and pesticides is not required for organic farming. On the other hand, users of organic farming methods may require more equipment of various types due to the emphasis on crop rotations and animal wastes as part of the overall system.

Likely Timing of Commercial Introduction

Controlled traffic farming and custom prescribed tillage may be introduced on a moderate commercial scale by the early 1990s. Both of these land management concepts require years of interdisciplinary research to: (1) develop the base of information required, particularly for custom prescribed tillage which requires information on soil dynamics and many other factors; (2) develop components, e.g., field and tillage transducers, and control algorithms, and control systems for tillage equipment; (3) integrate of components into a workable tillage system; and (4) prove their economic feasibility under a wide variety of land and climatic conditions.

The individual components may be developed in 2 to 3 years; their integration, testing, and manufacture into a commercial system is likely to take an additional 4 to 5 years. Commercial acceptance will depend upon the results of cost/benefit studies of the system or systems developed, along with the net income situation of farmers.

Conservation tillage practices and multiple cropping systems are likely to evolve steadily over the next decade as their benefits over conventional systems are proven and more widely publicized. This trend is occurring now, as more farmers become aware of the need to preserve long-term soil productivity. The development of conservation tillage methods, in particular, should continue to be stimulated by the potential savings afforded by reduced labor and fuel expenses, along with the availability of equipment and pesticides compatible with the heavy amounts of crop residues left on the soil surface.

Institutional Arrangements

Basic research on new soil tillage methods is undertaken by the National Tillage Machinery Laboratory, Agricultural Research Service, U.S. Department of Agriculture at Auburn, Alabama. The mission of the National Tillage Machinery Laboratory is to increase the efficiency and effectiveness of tillage and traction machinery systems by developing a better understanding of soil-machine and plant relations. The Agricultural Research Service also conducts land management and tillage and traction research at other locations such as Stoneville, Mississippi; Shafter, California; and Temple, Texas. The National Tillage Machinery Laboratory performs cooperative research with a number of universities, other ARS locations and with private industry.

Various universities also conduct land management/tillage research. Some examples include: Texas A&M (cable towing of field machinery), Iowa State University (soybean response to tillage and planting systems), University of Georgia (effects of soil compaction), Purdue University (effects of subsoil compaction on corn), and Ohio State University (conservation tillage).

John Deere and International Harvester also are involved in tillage research to some extent. For example, John Deere is interested in developing improved moldboard plows having reduced draft requirements. Other short-line machinery manufacturers also have developed specific implements for conservation tillage. For example, Howard Rotavator Company, Inc., has developed the Paraplow which is a conservation tillage tool designed to loosen subsoil while keeping virtually all crop residues on the surface to protect the soil.

While their research is not equipment-related, organizations such as the Council of Agricultural Science and Technology (CAST) have conducted considerable land management-related research. For example, CAST has published research reports on organic and conventional farming (1980); preserving agricultural land (July, 1981), implications of soil erosion (1982); and land resource use and protection (1975). Also, Dr. W.E. Larson and others in the Soil Science Department of the University of Minnesota have conducted considerable research on soil erosion and its effect on agricultural productivity across the United States.

Potential Primary Impacts

Soil Erosion and Crop Productivity

Perhaps the primary factor behind interest in new land management techniques is the increasing concern over soil erosion, and the consequent long-term effects on crop productivity. An economic factor related to soil erosion is the trend toward a more specialized agriculture over the past two decades. There has been a declining percentage of farms with livestock, and the percentage of cash grain farms has increased sharply.

However, it should not be implied that soil productivity declines in direct proportion to the rate of soil erosion. Larson (1983) indicates that some subsoils are nearly as conducive to crop growth as are the top soils above them. For example, deep loess soils such as Monona, found in western Iowa, produce essentially the same crop yield when eroded vs. when not eroded, assuming adequate fertilization levels on both. Monona soil is eroding at an estimated rate of 34 tons per acre per year. However, even with this high erosion rate, studies have indicated that if erosion continues at the present rate for the next 200 years, the potential productivity of the soil at the end of that time will be only 2 percent less than it is today (Larson, Pierce, and Dowdy, 1983).

Generally, if conditions remain relatively stable nationwide over the next 50 years, potential soil productivity is expected to be 5-10 percent less than in 1984. Losses in productivity would be greatest on slopes exceeding 6 percent, and when subsoil properties are unfavorable for crop growth. About 29 percent of United States crop land is on slopes steeper than 6 percent grade. On the generally fertile and deep soils of the Corn Belt, potential productivity will probably decline less than 10 percent over the next 50 years. However, in the Southeast United States, continued soil erosion would be more serious since these subsoils have major limitations in water-holding capacity, pH, and nutritional deficiencies.

The use of conservation tillage is just one part of an overall crop management system, as indicated in Figure 5. As indicated in this figure, many other factors such as fertility, planting depth, disease control, row width, etc., need to be considered in conservation tillage or with other new tillage concepts such as controlled traffic farming and custom prescribed tillage.

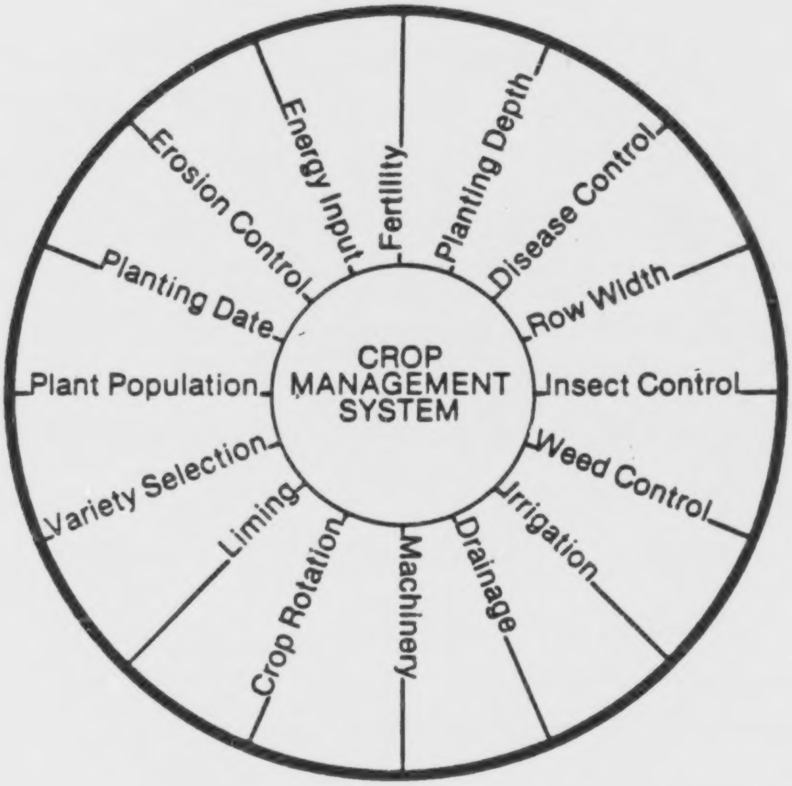

CROP MANAGEMENT SYSTEM
Fertility
Planting Depth
Disease Control
Row Width
Insect Control
Weed Control
Irrigation
Drainage
Machinery
Crop Rotation
Liming
Variety Selection
Plant Population
Planting Date
Erosion Control
Energy Input

FIGURE 5. COMPONENTS OF A TOTAL CROP MANAGEMENT SYSTEM (RANDALL, 1983).

Controlled Traffic Farming

Morling (1982) indicated the advantages and disadvantages of "controlled traffic" farming. Some of these advantages include the following:

A) A reduction in soil compaction in the crop zone and the ability to control compaction which results in:

1) Better water infiltration and storage of water
2) Better air void ratio within the soil, resulting in less impedance to root growth
3) Less soil erosion, nutrient, and chemical losses
4) No wheel track depressions to channel water run-off
5) Looser and dryer soil to warm up sooner in the spring, allowing earlier planting
6) Less tillage of soil required.

B) The provision of a compacted traffic path which results in:

1) Better tractive efficiency of powered wheels and less rolling resistance of unpowered wheels
2) Smaller wheels and tires required (less flotation)
3) Improved timeliness for planting and harvesting

C) An increase in profits for the farmer by:

1) Increasing crop yields
2) Reducing fuel costs for tillage and transport
3) Reducing tire costs (size and wear)
4) Reducing fuel costs for drying crops, through more timely harvesting

Some disadvantages of controlled traffic farming include:

A) Careful control of all field equipment is necessary and more management is required for field operation because:

1) Specific traffic paths must be developed in all fields with roadway headlands
2) All machines for crop production, harvest and crop input and output must fit the path and operate on it or stay on the roadway at the ends of the field
3) A system of automatic guidance is needed to maintain location of paths
4) Reduced tillage can result in more crop diseases
5) Some initial investment is needed

B) Less crop area is available because:

1) Crops cannot be grown in the headlands
2) Crops should not be grown close to the traffic path.

The question of potentially higher crop yields versus reduced land in production with controlled traffic farming must be addressed. For example, incorporation of traffic lanes 2-feet wide, spaced at 30-foot intervals over 1 square acre of crop land would reduce the amount of cultivated land by approximately 7 percent. An additional 5-15 percent of land would be removed from cultivation by not growing crops on the headlands at the end of the rows. Crop yield increases under controlled traffic farming must more than offset the reduction in cultivated areas to make controlled traffic farming feasible.

Organic Farming

Organic farming may be a strategy chosen by certain farmers to lower production costs, adjust to higher energy prices, or lessen the uncertainty of energy-intensive input supplies. In some instances, these farmers may be able to substitute family labor for farm machinery or for herbicides to control weeds. Organic farming methods also may be attractive to some new entrants into agriculture who lack funds for getting started (CAST Report No. 84, 1980).

The economic impacts of an increase in adoption of organic farming would depend largely on the degree and extent of adoption. Limited adoption, in which farmers might take advantage of a special market under certain economic conditions, would probably have little direct effect on consumers or the agriculture community. Widespread adoption, on the other hand, would have large impacts on both. Some of these impacts were indicated in a report by the Council for Agricultural Science and Technology (1980).

- Comparison of crop yields in organic and conventional systems have indicated yield reductions under organic farming ranging from 7 to 44 percent. This does not include data from organic farms on which outside sources of manure or municipal sludge are available. Farming in a mixed grain-livestock system without nitrogen fertilizers and pesticides would reduce aggegegate yields by 15-25 percent assuming little or no change in cropping patterns. A shift in cropping patterns on cash grain or vegetable farms to grow more nitrogen fixing legumes would lead to reduced production of grain and vegetables due to the smaller areas devoted to these crops in any given year. On the other hand, the decrease in production probably would increase aggregate farm income because the percentage increase in farm prices would be expected to exceed the percentage decrease in production.

- A shift in production to more legumes is estimated to require 18-33 percent more of the same kind of land to produce the output obtained by conventional farming practices. Because there is little idle land where soils and climate are favorable, the additional land would be less productive and more of it would be needed.

- Prices for crops that are intensive nitrogen fertilizer users (for example, corn) would increase sharply, whereas prices for legume crops might decline. Regions without adequate organic matter sources or where legume sources are not usable, such as the dryland wheat producing areas, also would be negatively effected.

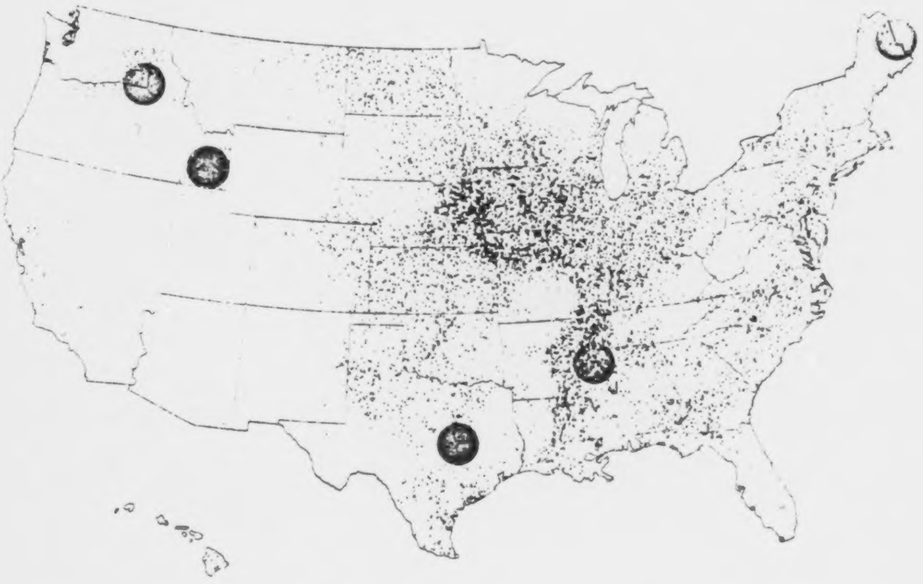
- Each 1 percent decrease in crop production would increase estimated "farm-gate" prices by approximately 2 to 4 percent. The resulting increase in retail food prices is approximately one-third of the farm-gate price increase or from 0.5 to 1.5

percent for each 1 percent decrease in production. A 10 percent decrease in agricultural output would result in an estimated 20 to 40 percent increase in farm prices, and a 7.5 to 15 percent increase in retail food prices.

Perhaps the greatest incentives to adopt new land management practices are in those areas of the United States affected by serious erosion. These areas are indicated in Figure 6, (U.S. Department of Agriculture, 1980). Therefore, some form of conservation tillage, controlled traffic farming, custom prescribed tillage, or multiple cropping may be employed as one means of reducing soil erosion losses. Although the supply of United States farmland is adequate to meet domestic food requirements, the ability to meet both domestic requirements and export demand over the next few decades is questionable. Given the importance of land for food production, and uncertainties regarding future land supply/demand balances, these forms of land management are an important "insurance policy" to provide for future contingencies.

The colored areas on the map below, which shows total tons of sheet and rill erosion on cropland, indicate several of the more serious erosion areas in the country.

Cropland Sheet and Rill Erosion: 1977
Total for United States is 2,000,000,000
Data for Alaska not available
1 dot = 250,000 tons



- *The Palouse*, covering parts of Washington, Oregon, and Idaho, is dryfarmed to wheat, barley, peas, and lentils. Most of the cropland is hilly, with slopes of from 15-25 percent. Runoff from melting snow and heavy rains causes erosion of 50 to 100 tons per acre.

- *Southeastern Idaho* cropland is planted in hard red wheat one year and left fallow the next to conserve moisture. Erosion occurs during intense summer rainstorms and even more destructive rains in late winter, when a thawed layer of soil moves downhill over frozen subsoil. Annual erosion may reach 16 tons per acre per year on 35 percent slopes.

- *Texas Blackland Prairie* is an important farming area, with two-thirds of the land in crops, mainly cotton and grain sorghum. Rainfall averages 30 to 50 inches a year on the gently rolling land. Many soils in the area are highly erodible, and erosion is appreciably higher than the national average.

- *Southern Mississippi Valley*, including parts of five states, is about one-third cropland, much of it sloping to steep. The soils are deep, fertile, productive, and erodible. Many row crops are grown without adequate conservation practices, and annual soil losses on much of the land reach 20 tons per acre or more.

- *The Corn Belt States* experience some of the highest erosion rates in the country: in 1977, Iowa cropland lost an average of 9.9 tons of soil per acre; Illinois, 6.7 tons per acre, and Missouri, 10.9 tons per acre.

- *Aroostook County, Maine*, is famous for its potatoes. They are grown on slopes ranging from nearly level to 25 percent. The upper 2 feet of soil have been lost since cultivation began, lowering crop yields. Some sloping fields are losing as much as an inch of soil a year.

FIGURE 6. SOME SERIOUS EROSION AREAS IN THE UNITED STATES.

Source: U.S. Department of Agriculture, Soil Conservation Service. "America's Soil and Water: Condition and Trends", December, 1980.

References

(1) "Conservation Tillage Information Center", Crops and Soils Magazine, February, 1984, pp 5-6.

(2) Cooper, A.W., A.C. Trouse, W.T. Dumas, and J.R. Williford, "Controlled Traffic Farming, A Beneficial Cultural Practice for Southern U.S. Agriculture.", paper presented at the Winter Meeting of the American Society of Agricultural Engineers, Paper No. 83-1547, December 13-16, 1983.

(3) Council for Agricultural Science and Technology, Land Resource Use and Protection, Report No. 38, January 28, 1975.

(4) Council for Agricultural Science and Technology, Organic and Conventional Farming Compared, Report No. 84, October 1980.

(5) Council for Agricultural Science and Technology, Preserving Agricultural Land: Issues and Policy Alternatives, Report No. 90, July 1981.

(6) Council for Agricultural Science and Technology, Soil Erosion: Its Agricultural, Environmental, and Socialeconomic Implications, Report No. 92, January 1982.

(7) Dickey, E.C., T.R. Peterson, J.R. Gilley and L.N. Mielke, "Yield Comparisons Between Continuous No-Till and Tillage Rotations", American Society of Agricultural Engineers. Published Paper No. 7083. 1983.

(8) Erbach, D.C., and Lovely, W.G., "Machinery Adaptations for Multiple Cropping" Multiple Cropping, ASA Sprecial Publication No. 27. M. Stelly, ed. pp 337-347.

(9) Johnson, C.E., C.B. Elkins and R.L. Schafer, "Teaming with Nature for Conservation Tillage: A Concept," paper presented at the Summer Meeting of the American Society of Agricultural Engineers, Orlando, Florida, June 21-24, 1981. ASAE Paper No. 81-1019.

(10) Larson, W.E., F.J. Pierce and R.H. Dowdy, "Soil Erosion and Productivity: A Rational Look at a Complex Situation," Crops and Soils Magazine, August-September, 1983, pp 19-20.

(11) Morling, R.W., P.E., The Pros and Cons of "Controlled Traffic Farming," paper presented at the Summer Meeting of the American Society of Agricultural Engineers, Paper No. 82-1043, June 27-30, 1982.

(12) Morrison, J.E., Jr., T.J. Gerik, "An Argument for Wide Beds with Conservation Tillage", paper presented at the Winter Meeting of the American Society of Agricultural Engineers, Paper No. 83-1543, December 13-16, 1983.

(13) Perkins, Jerry, "The Revolution in Tillage", Enterprise, June, 1983, pp 10-12.

(14) Randall, W.G., 'Conservation Tillage: A Plan for Winning the Profit Game," Crops and Soils Magazine, June-July, 1983, pp 18-20.

(15) Reagan, J.J., "Strip Intercropping: Worth A Look," The Furrow, November-December, 1983, pp 18-19.

(16) Schafer, J.J., S.C. Young, J.G. Hendrick, C.E. Johnson, "Control Concepts for Tillage Systems," Paper presented at the Winter Meeting of the American Society of Agricultural Engineers. Paper No. 81-1601, December 15-18, 1981.

(17) Taylor, J.H., "A Controlled-Traffic Agricultural System Using a Wide Frame Carrier," The International Society for Terrain-Vehicle Systems, Inc., International Conference, August 16-20, 1981, Calgary, Alberta Canada.

(18) U.S. Department of Agriculture, "America's Soil and Water: Condition and Trends," Soil Conservation Service, December, 1980.

(19) Zahradnik, Fred, "A New Conservation Plow," The New Farm, February, 1984, pp 26-27.

Background Paper No. 17

Soil Erosion, Productivity, and Tillage

George R. Foster
Agricultural Research Service
U.S. Department of Agriculture

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

SUMMARY

The quantity and quality of harvested crops depend on the amount of land, the suitability of its soil for growing crops, the biology of crops, and the environment. Most crops are grown on clean, tilled soil, leaving the soil exposed and unprotected. Severe erosion can result, and over time so much soil is lost that crop yields decrease and some land may be forced from agricultural production. Excessive soil erosion is estimated to occur on about 30 percent of U.S. cropland, but its effects on productivity are thought to have been masked by new technological inputs like hybrids, fertilizers, and chemicals.

Soil erosion is the detachment of soil particles by the erosive effects of rain, surface runoff, and wind. When erosion removes soil more rapidly than it can be formed, soil becomes thinner with less rooting depth for crops. When the topsoil becomes thinner than the tillage depth, subsoil becomes mixed with topsoil during tillage, degrading the soil. Erosion also removes the fine silt, clay, and organic particles most important for good soil quality. The resultant increase in sand content of the soil reduces the soil's productive potential. Sediment from erosion can create off-site problems through deposits in road ditches, reservoirs, and river channels. Sediment or the chemicals it transports can also pollute off-site air and water.

Four major lines of research on erosion control are proposed: (1) improved conservation farming systems, (2) improved methods for assessing erosion's impacts, (3) evaluation of the potential for restoring productivity to severely eroded soils, and (4) improved understanding of how to use public policy to encourage soil conservation.

Of all factors affecting erosion, crop residue left on the soil surface is most effective in reducing erosion. Research on improved conservation systems will thus emphasize conservation tillage, including reduced tillage, minimum tillage, and no-tillage. The differences between the types of conservation tillage lie in the amount of soil disturbance and in the amount of crop residue left on the soil. When matched to soil conditions, conservation tillage can potentially provide greater economic return and often equal or greater yield than that of conventional tillage. For example, no-tillage works well on well-drained, sloping soils but not on cool, poorly drained soils in the Corn Belt. Although conservation tillage has the fewest drawbacks of all erosion control practices, considerable development of the method is still required.

The degree of erosion's impact is a major issue that needs a conclusive answer. The principal tool used to estimate erosion by water is the Universal Soil Loss Equation. The tool for estimating wind erosion is the Wind Erosion Equation. Recent developments in erosion theory and the availability of powerful, portable computers make possible new methods that are more detailed and more accurate for estimating erosion over a varied landscape, erosion from individual storms, and average annual erosion. Remote sensing technology and special image processing equipment will aid in the collection of data. New field studies have been initiated and several mathematical modeling techniques have been developed to evaluate the effect of erosion on crop yield.

If eroded soils can reasonably be reclaimed, the problems of erosion may be less serious than presently thought. Current research in the Piedmont region shows that conservation tillage and multiple cropping can be used to restore productivity. Much research must still be done in this area.

Although several practices are available for controlling erosion, many have drawbacks that hamper adoption by farmers. As a result, various policy alternatives are used and have been suggested to provide incentives to farmers to implement soil conservation. Improving the use of public policy will entail the incorporation of major analytical tools into an integrated package compatible with affordable computer resources. Such tools will include models for climate, erosion, water quality, crop yield, pests, and economics.

The major potential impact of this technology on agriculture will be significantly improved erosion control with little loss, if not gain, in crop yield, improved water quality, improved farmability, and increased profit. It is hoped that this technology will provide farming systems with enough positive benefits that erosion control becomes a side benefit.

Soil Erosion, Productivity, and Tillage[1]

G. R. Foster[2]

I. INTRODUCTION

A. Scope of Topic

Soil is a basic resource used as a media for growing crops for animal and human nutrition. The quantity and quality of harvested crops depends on both quantity and quality of land and the suitability of its soil for growing crops. Before the eastern prairies and forestlands were opened to agricultural production, little soil erosion occurred because natural cover provided protection against erosive rains (Trimble, 1977). Most crop production is accomplished on clean, tilled soil, which leaves the soil exposed and unprotected. Severe erosion results, and over time, so much soil can be lost that crop yields decrease (USDA, 1981c; Lawson et al., 1983). In extreme cases, erosion can be so severe that land can be forced from agricultural production (Trimble, 1974). The classic U.S. example is the major shift of land from cotton production to forestry at the turn of this century in the Piedmont area of the Southeast (Trimble, 1974). Excessively eroding lands need to be identified and treated before erosion has progressed so far that land is forced from production, or before excessive crop yield potential has been permanently lost, or before restoration of productivity becomes unreasonably difficult, even when the damage is not permanent.

---

[1] Contribution from the USDA-Agricultural Research Service, National Soil Erosion Laboratory in cooperation with the Purdue Agricultural Experiment Station.

[2] Hydraulic Engineer, USDA-Agricultural Research Service, and Associate Professor, Agricultural Engineering Department, Purdue University, W. Lafayette, IN.

This paper on the broad topics of soil erosion, productivity, and tillage emphasizes technology to determine the impact of soil erosion on productivity and use of tillage practices to control erosion. Obviously, many other factors such as management of soil, water, and fertility affect a soil's productive potential, but other panel members will address these issues.

B. Definition of Topic

Soil erosion is the detachment and transportation of soil particles by the erosive agents of rain, surface runoff, and wind. Some of the eroded particles, called sediment, will be transported only a short distance before being deposited. The sediment leaving watersheds ranging from as small as within field areas to river basins is called sediment yield. Sediment yield may cause off-site damage where sediment is deposited like road ditches, flood plains, reservoirs, and river channels (ASCE, 1975). Also, it may pollute receiving waters by being a carrier of polluting chemicals like some pesticides, and it can be a pollutant itself in water and air. Airborne dust that causes respiratory problems is an example of sediment being a pollutant. Recent and preliminary evaluations suggest that short-term economic losses from off-site sedimentation may approach or exceed that from on-site damages caused by erosion (Crosson, 1984; K. W. Flach, USDA-Soil Conservation Service, Washington, D.C., personal communication, 1984).

On-site damage caused by soil erosion is from its impact on the quality of soil for growing crops (Larson et al., 1983). Where erosion removes soil more rapidly than it is being formed, soil becomes thinner and provides less rooting depth for crops. Erosion can also change surface soil properties. Most soils are layered and the topsoil layer is usually the layer having the best properties for growing plants while subsoil layers are usually less desirable. If erosion removes soil more rapidly than new topsoil is formed from subsoil, topsoil will diminish. When the topsoil becomes thinner than the tillage depth, tillage begins to mix subsoil with topsoil, which often degrades the soil. Over time, excessive erosion can remove the entire topsoil. Erosion is also a selective process and preferentially removes fine silt, clay, and organic particles, the soil fractions most important for good soil quality (Foster et al., 1985b). This selective removal of fines increases the sand content of the remaining soil, which can reduce the soil's productive potential.

Soil loss tolerance values have been assigned to most soils (Shertz, 1983). If the average annual erosion rate of a soil exceeds its soil loss tolerance, the soil is said to be excessively eroding (Wischmeier and Smith 1978; Shertz, 1983). Erosion is diffuse and occurs at widely varying rates across the landscape. Since assessment of erosion by measuring it at numerous field sites is impractical, mathematical prediction methods, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) in particular, are used to estimate erosion at sample points. Almost 200,000 samples on non-Federal U.S. land were used in a 1977 USDA national resources inventory and the number of sample points was expanded to more than 1 million for the recent 1982 inventory (USDA, 1981a; NRC, 1984; Lee, 1984). According to analysis of the 1977 data, almost 30 percent of the U.S. cropland is eroding at rates greater than soil loss tolerance implying that this land is experiencing excessive degradation from erosion (USDA, 1981a).

Many practices are available to control erosion, but the application of a specific practice is directly affected by crop production patterns in a region. Rotations among row crops, small grain, and meadow can be an effective erosion control practice on a dairy farm, but not useful on a cash grain farm because no livestock are available to utilize the hay from the meadow. On the cash grain farm, conservation tillage would likely be the primary erosion control practice, while neither rotations nor conservation tillage might be practical on a vegetable farm. Terraces, strip cropping, farming on the contour, and grassed waterways are practices that support cultural practices like rotations and conservation tillage. Properly designed practices for a given field often involve a system of practices including conservation tillage to control sheet and rill erosion, grassed waterways to control erosion in concentrated flow areas, and impoundment terraces to control sediment yield from the field. However, in general, conservation tillage is often the preferred erosion control practice (Moldenhauer et al., 1983). In 1981 slightly more than one-fourth of the harvested cropland was estimated to be in conservation tillage (Moldenhauer et al., 1983).

Many forms of conservation tillage exist including reduced tillage, minimum tillage, and no-tillage (Moldenhauer et al., 1983). Generally, the difference among them is the amount of soil disturbance and amount of residue left on the surface after tillage. For this discussion, conservation tillage represents any tillage system that reduces erosion from row crops farmed by moldboard plowing, secondary tillage, and planting, or its equivalent for small grain, vegetables, or other crops. Of all factors affecting erosion, crop residue left on the soil surface is most effective in reducing erosion (Wischmeier and Smith, 1975). Therefore, when crop residue is harvested for off-site use, sufficient residue should be left on the field for adequate erosion control and maintenance of soil organic matter (Larson et al., 1977). However, other cropping systems like rotations involving meadow should not be overlooked. Obviously, the meadow controls erosion while it is in place, but in addition, it has a residual influence on the soil after it is plowed. For the first year after a high production meadow is plowed, the soil is only about 50 percent as erodible as it is in continuous row crops (Wischmeier and Smith, 1978).

Many factors affect erosion and a variety of erosion control practices can be used to manipulate these factors. One simple system is not optimum for all conditions; rather erosion control practices should be tailored to the specific site. For example, a 20 percent cover of residue might be adequate to control erosion on a particular 5 percent slope. However, if the same soil on this slope occurs on a 10 percent slope of the same length in the same locale, about 60 percent cover would be required to keep erosion at the same rate as that with the 20 percent cover on the 5 percent slope (Wischmeier and Smith, 1978).

Several erosion control practices have drawbacks. Some reduce yield, some are costly, some inconvenience farming operations, some slow plant emergence and early growth, and some encourage pests (ASAE, 1981). The principle often used in selecting an erosion control practice for a specific site is to select one that provides adequate erosion control for the given soil while minimizing problems.

Since the 1930's, the public has been concerned about soil erosion and its impact and has provided for both Federal and State agencies to grant technical and financial assistance at the land-user level. These agencies include the USDA-Soil Conservation Service, Agricultural Stabilization and

Conservation Service, Extension Service, and local Soil and Water Conservation Districts (USDA, 1981a).

The public has an obvious interest in protecting soil so that sufficient land of adequate quality will continually be available for producing food. Erosion slowly degrades soil, and little immediate impact is felt when excessive erosion occurs in any single year. Consequently, short-term benefits from conservation may not be great. Therefore, since soil conservation may not always pay in the short run, public financial support is seen as necessary to pay for soil conservation that will benefit future generations (CAST, 1982).

C. Major Lines of Research

The major lines of research that will likely "pay-off" by 2000 include:

1. Improved conservation farming systems.
2. Improved methods for assessing erosion and its impact.
3. Improved methods of restoring productivity to eroded land.
4. Improved understanding of how to use public policy to accomplish soil conservation objectives.

The logic behind the major lines of research is the following. The extent of erosion problems and their impact must be identified in order to both effectively use and preserve a critical natural resource, soil; hence the reason for having a major line of research on assessing erosion and its impact. Given that erosion is a problem, and current assessment technology suggests that it is on about 30 percent of U.S. cropland, effective erosion control practices are needed. Hopefully, science can develop these practices so that they will have no major drawbacks and so that they will be readily accepted because their benefits exceed their drawbacks. These benefits may include increased yield, improved land value, improved timeliness of farming operations, increased profit, and improved farming convenience. If this can be achieved, dependence on pulbic policy as an incentive toward achieving on-farm implementation of erosion control practices will decrease. However, the likelihood is that public policy will still be an important factor in soil conservation in 2000. Therefore, analytical methods are needed to evaluate the potential of success of given policies at all scales from the farm to the national level.

Portions of many fields are eroded so much that crop yield on those areas are significantly depressed (White et al., 1984). Total farm yield could be increased if these areas could be practically treated and restored to a greater productivity. Furthermore, if widespread reclamation of severely eroded land is feasible (Bartelli, 1980), reclamation would provide another alternative for dealing with erosion problems. The possibilities, costs, and associated risks of reclamation need to be fully known before a policy is adopted whereby soil is allowed to excessively erode expecting that reclamation can restore it to productivity.

II. CURRENT STATE OF THE ART

A. Erosion Control

As previously mentioned, many methods of controlling soil erosion are available, but many have limits related to yield, profit, timeliness, maintenance, and other factors. An example illustrates the problem. A farmer may own a farm having erodible soils on steep slopes. One way of protecting the farm is to put it in forest, which extensively occurred on eroded Piedmont land (Trimble, 1974), but such a land conversion may be unacceptable to this farmer because of the long time required for an economic return. Thus, one particularly effective erosion control practice for this situation is impractical, at least from this farmer's perspective. However, an economically sound and effective practice might be no-till conservation tillage by double cropping wheat and soybeans if the farm happens to be in the Southeast (Moldenhauer et al., 1983). By adopting conservation tillage, the land can remain in crop production. This example involved a major land use conversion, but more typical examples could involve the difficulties of a cash grain farmer changing to a meadow crop to control erosion.

Conservation tillage has emerged over the last 15 years as a group of erosion control practices having the fewest drawbacks (Moldenhauer et al., 1984). A major advantage of conservation tillage is that these systems do not restrict crop selection in the way that conventionally tilled crop rotations would require a meadow crop for erosion control. However, considerable development has been and still is required for conservation tillage (Van Doren et al., 1981). For example, in the beginning, equipment was not available that could work effectively in residue. Weeds, insects, disease, and reliable stand establishment on wet and cool soils have been problems (Van Doren et al., 1981). Generally conservation tillage requires a greater reliance on chemicals and more intensive management. Nevertheless, conservation tillage is being increasingly adopted and more commercial products and information on how to successfully use conservation tillage are available to the farmer (Moldenhauer et al., 1983). When conservation tillage systems are carefully matched to soil conditions, conservation tillage potentially can provide greater economic return and often provide equal or greater yield than that from conventional tillage (Doster et al., 1983). The tillage system should be matched to the soil because no-till works well on well drained, sloping soils but not on cool, poorly drained soils in the Corn Belt (Doster et al., 1983).

B. Assessing Erosion and its Impact

The principal tool used to estimate erosion by water is the Universal Soil Loss Equation (USLE), an equation that is now 25 years old (Wischmeier and Smith, 1978). The USLE was empirically derived from more than 10,000 plot-years of data from natural runoff field plots plus perhaps an equivalent of 1,000 plot-years of rainfall simulator data. Initially the equation was derived for the eastern United States, but recently it has been extended to the West. Research continues to develop and refine the equation.

The USLE, which estimates average annual sheet and rill erosion, was originally intended to be used as a guide in selecting conservation practices, but it is now used for many more applications like national inventories of erosion (USDA, 1981a). Its simple mathematical relationships makes it easy to use, but its simplicity also limits its accuracy. Recent developments in erosion theory and the availability of powerful, portable computers make possible more detailed and accurate methods for estimating erosion over a varied landscape, erosion from individual storms, and average annual erosion; especially in the Western United States (Foster et al., 1984a).

The Wind Erosion Equation for estimating average annual soil loss from wind is equivalent to the USLE (Woodruff and Siddoway, 1965). It too is an empirical equation that is used to select conservation practices and to assess rates of wind erosion.

The recent 1982 national assessment involved computing erosion at more than 1 million individual sample points across U.S. non-Federal land (USDA, 1981a; Lee, 1984). Much of the information was gathered from on-site visits, which obviously made the inventory expensive. Invariably, more information from inventories is desired than can be provided. An example is the need for topographic data to compute erosion and deposition over land profiles through a sample point or over the small watershed that contains the sample point. Remote sensing provides an opportunity to rapidly collect data that can be used to estimate current erosion rate. Special image processing equipment, computers, and computer programs provide the potential for expanding inventories and improving their accuracy. Remote sensing was not extensively used in the 1982 inventory, but the USDA-Soil Conservation Service plans to make much greater use of it in the 1987 inventory (NRC, 1984).

Present soil loss tolerance values were mostly developed in the mid 1950s, a period when crop production practices were quite different from present ones (Schertz, 1983). The issue of the impact of erosion on productivity is controversial. Some point out that crop production has increased even; while erosion has continued or increased during the last 20 years inferring that erosion has not greatly damaged the productivity capacity of soils (Bartelli, 1980). Others note that the increase in production is from inputs of technology including new hybrids, increased fertilization, and improved management, which has masked the loss of potential productivity caused by erosion (USDA, 1981c).

Available scientific data do not conclusively settle these claims, and assessments of the impact of erosion on productivity cannot be made with the desired accuracy. New field studies have been initiated and several mathematical modeling techniques have been developed to evaluate the effect of erosion on crop yield (USDA, 1981b; Pierce et al., 1984; Williams et al., 1983; ASAE, 1985). These models need to be validated, but the slowness of erosion, its delayed impact over decades, and the variability of climate make collecting the required data and validation of the models very difficult.

C. Reclamation of Eroded Land

Erosion research in the 1930s and 1940s emphasized reclamation of eroded land (Smith et al., 1945). Most recent reclamation research is on reclaiming surface mined land (Barrows, 1976), although current research on eroded soils in the Piedmont region shows that conservation tillage and multiple cropping can be used to restore productivity (House et al., 1984; Langdale, 1984). Other reclamation research is on land graded to improve drainage, irrigation efficiency, and for terracing, which has removed all topsoil in some field areas during construction (Reuss and Campbell, 1961). Some soil specialists claim that many soils degraded by erosion can be easily reclaimed, especially deep loess soils (Bartelli, 1980). The potential of restoring the productivity of eroded soils and reclamation technology for doing it needs to be understood, because if eroded soils can be reasonably reclaimed, the problems of erosion might be less serious than presently thought.

D. Use of Public Policy

Public policy is a tool for encouraging implementation of soil conservation. A recent CAST (1982) committee suggested several public policy options, but it did not evaluate their likely effectiveness. Before a given policy is implemented, its impact needs to be evaluated from the farm to the national level. Such evaluations usually involve the use of large linear programming models. For example, a model of this type was used to show how agricultural production would shift if certain erosion control restraints were implemented (Wade and Heady, 1978). These models are often very general and do not apply to areas as specific as particular counties. However, they are very powerful tools for evaluating the potential national impact of various public policies. Similar models are available for local and farm situations (McCarl and Pheasant, 1983).

III. MAJOR BREAKTHROUGHS NEEDED

A. Conservation Systems

Research on conservation systems is a multidisciplinary problem. Research is needed on soil properties and crop growth and how they can be managed and improved through a variety of cultural practices including tillage, timing of operations, crops grown, fertilization, residue management, and pest control and how to combine these practices for optimum plant growth (Van Doren et al., 1981). Conservation tillage creates plant/soil environments that differ from that of conventional tillage (Tollner et al., 1984). Cropping systems must be studied in their conservation tillage environment rather than continuing to adapt information from research using conventional tillage. The present main emphasis with crop variety development, for example, seems to be to conduct research on only the best soils. This research need is especially true with respect to weeds, insects, disease, seed germination, and stand establishment. Therefore, some shifts in research from conventional tillage systems to conservation tillage systems is needed or at least new research on conservation tillage needs to be added. Furthermore, more research is needed to improve crop production on problem soils, especially those that are cool and poorly drained. Improved and a wide range of satisfactory conservation tillage systems will evolve, and no major breakthroughs are foreseen, but steady research progress is necessary.

B. Assessing Erosion and Its Impact

1. Assessing Erosion. Recent research has shown that neglect of the variation of erosion and deposition over the landscape can greatly affect evaluations of the impact of erosion (Perrens et al., 1985). Erosion varies greatly over the rolling topography of many fields, and erosion rates for significant portions of a field may be several times the average erosion rate for the field. Furthermore, as much as 70 to 80 percent of the sediment eroded in some fields can be deposited within the fields (Piest et al., 1975). Loss of crop yield is nonlinearly related to erosion, and therefore, with the large variation in erosion and deposition, an average erosion rate for a field may poorly indicate average crop yield loss for the field. The needed breakthroughs include ways of efficiently computing erosion, deposition, and crop yield at all points over a field. Since such methods will require much data input, improved ways to collect, assemble, manage, and interpret large data bases must be found. This technology will use remotely sensed data, computerization of existing data bases, collection of new data such as on landform, computer hardware, and computer software.

2. Impact of Erosion. The degree of erosion's impact is a major issue, and one that needs a conclusive answer. Yet erosion is a slow process and the impact of erosion over the short term (a few decades) is masked by climatic variability and technological advancements (USDA, 1981c). The problem does not allow waiting to see if erosion actually proves to be as serious as it is thought to be. If it is, erosion's damage is irreversible for some soils. On the other hand, unnecessarily restrained production may also be undesirable. Extensive and high quality field data are needed to experimentally evaluate the impact of erosion on productivity (USDA, 1981b), and a major challenge is

to obtain these data in a relatively short time (a decade). However, long-term experiments should be established and maintained over a few decades, which will require a long-term funding commitment for this research.

A companion approach to field experiments is the use of climate, erosion, soil, and plant models to evaluate how erosion affects productivity, a very recent technology (USDA, 1981c). Even when these models are based on the best scientific principles, experimental data are needed to validate them. In one analysis of the impact of erosion, three different models lead to the same general conclusion concerning the short-term impact of erosion on crop yield (Perrens et al., 1985). However, their results differed substantially for the long term, and the "rightness" of a specific model still must involve scientific judgment. While uncertainty in the evaluation of the impact of erosion on productivity will be reduced by 2000, likely the issue will not be conclusively settled.

3. Field Implementation of Practices. A farming system selected for specific fields and farms needs to meet several criteria including erosion control and water quality maintenance. Other important factors include adaptability of a particular system to a given climate, soil, and topography. Obviously, the system should be profitable and meet several other criteria that a farmer would consider to be important. Many of the considerations interact so that the best choice for a farming system is often not obvious. Therefore, the farmer and those providing him with technical guidance needs analytical tools to guide the selection of a farming system. One analytical tool with much potential is a branch of artificial intelligence known as "expert systems" (Hays-Roth, et al., 1983). The computer software needed for an expert system to be used as a guide for selecting a conservation

farming system for a particular farm should be developed to run on computer hardware likely to be available to the farmer and his consultants.

C. Reclamation of Eroded Land

One of the major breakthroughs needed in research on reclamation of eroded land is to establish the conditions and feasibility of restoring lost productivity to eroded soil (Van Doren et al., 1981). Second, methods for reclaiming eroded land are needed, and their costs need identification. Results of research on reclamation of surface-mined land, soil management, and the relation of crop yield to soil properties has application to restoration of productivity to severely eroded cropland.

D. Use of Public Policy

One of the major breakthroughs needed to improve the use of public policy to encourage soil conservation is the assembly of major analytical tools into an integrated package compatible with reasonable computer resources. Some of the analytical tools in the package would include models for climate, erosion, water quality, crop yield, pests, economics, and social factors that compute crop production variables as they vary in time and space. Furthermore, large data bases are needed to drive these models. Since a single model of the set can require large computer resources, a challenge is to develop powerful analytical tools that operate within affordable computer resources. Once assembled, such models will need validation. Research is also needed to better understand how public policy affects adoption and maintenance of soil cnservation (Korsching et al., 1983), because some past policies have not been highly effective (GAO, 1983).

IV. INSTITUTIONAL ARRANGEMENTS

Managing and protecting soil resources is viewed as a joint and partnership effort involving the farm operator, land owner, and local, State, and Federal units of government (USDA, 1981a). Within government, especially the Federal Government, several agencies are involved. As expected, representatives of these agencies and private organizations express research needs. Frequently research, action, and regulatory agencies work together to develop needs and plans, evaluate research progress, and apply the research findings (USDA, 1984).

A. Federal Research Agencies

A significant role of Federal research agencies is to support Federal action agencies. Furthermore, erosion problems are national in scope so that principles learned in one area have application in many other areas. Although certain regions like the Pacific Northwest have unique problems, Federal agencies can lead research in developing basic and fundamental information that can be developed and adapted to local conditions. Some of the needed research will be long-term at several locations that must be well coordinated.

B. State Agricultural Experiment Stations and Land Grant Universities

State Agricultural Experiment Stations and their associated Land Grant Universities play the major role in adapting technology to local conditions. New conservation systems are much more management intensive and therefore sensitive to local conditions than are conventional systems. The Experiment Stations will define the conditions needed to be met in each region of a

State. Obviously these stations can also maintain long-term field experiments in cooperation with Federal agencies, and they can study specific problems using financial support from contracts, grants, and specific cooperative agreements as well as State funded support.

C. Public and Private Universities

Public and private universities can research erosion, productivity, and tillage problems, but their best contribution seems to be on specific problems of a relatively short duration, unless of course, they are provided with long-term, continuous funding.

D. Non-USDA National Laboratories

National laboratories like the Los Alamos, Oak Ridge, and Lawerence Livermore National Laboratories have scientists working in areas related to erosion, crop productivity, computer modeling management and analysis of large data bases, and special research procedures involving radionuclide tracers. Such laboratories can contribute on specific problems.

E. Private Industry

Private industry, especially the agricultural chemical, fertilizer, farm equipment, and seed companies, play major roles in developmental research where commercial products are developed to meet the requirements and needs as defined by research principally sponsored and conducted by public research agencies.

F. Extension Service and Federal Action Agencies

The Extension Service and other technology delivery agencies like the USDA-Soil Conservation Service will play a major role in the adoption of technology resulting from this research. The technology will need to be dispensed to a wide and varied audience who will often be individual farmers on individual land units. Consequently, the form of the technology must be both usable and deliverable. Therefore, the agencies responsible for technology delivery need to be partners with research in the review of the research along the way, and researchers need to interact with these agencies as the technology is finally packaged for delivery.

G. Special Interest Groups

Special interest groups, Soil and Water Conservation Districts in particular, play a major role in soil conservation. In many States, these districts are units of State government. They significantly influence public policy and they provide local involvement and a local agency for carrying out soil conservation policy.

H. Relationship of Groups

Interaction and interchange among the groups must occur. In the same way that crop production is recognized to be an interrelated system, so should research, development, delivery, and application of technology, which requires an integrated system of agencies.

V. LIKELY TIMING OF COMMERCIAL INTRODUCTION

Rather than a specific date of introduction of technology from this research, implementation of the technology is and will continue to be evolutionary. Although conservation tillage has limitations in certain cases, it is being regularly adopted on farms (Moldenhauer et al., 1983). This factor plus the increased availability of commercial equipment and products and information developed specifically for conservation tillage will accelerate its rate of adoption. Certainly by the year 2000, conservation tillage could well be used on most current land judged to be eroding excessively. Determination of whether or not erosion is being satisfactorily controlled will still require periodic inventories. Several forms of conservation tillage exist and not all provide adequate erosion control in difficult situations.

Significant improvement in methods to estimate erosion can be expected by 2000. Just recently, the USDA-Soil Conservation Service has identified this as a major research need (USDA, 1984), and the USDA-Agricultural Research Service has presented its initial plans to develop a next-generation erosion prediction method (Foster et al., 1985a). The new method should be usable by 1995. In addition, current methods will also be refined. Computer hardware and software will be available to field level technicians that will allow use of much more powerful analytical tools. Some of these new tools will use expert systems from artificial intelligence.

Main-frame computing capability will grow and become cheaper, and analytical tools will be developed for them that will allow many more public policy options to be evaluated for their impact on areas ranging from the national to the farm level. Several large data bases like data from the 1982

USDA natural resources inventory will be available on computers that can be readily accessed by a variety of users for a variety of purposes (NCR, 1984). The Corps of Engineers' implementation of a large soils data base from the USDA-Soil Conservation Service indicates that this trend is under way (Riggins and Goran, 1983).

The relative importance of remote sensing will grow, but so far it has failed to meet its promises (NCR, 1984). However, it will likely become an important practical tool used in conjunction with other tools to monitor and inventory soil and plant resources.

By the year 2000, the scientific community will have reached a consensus on how much erosion affects productivity. Technology like detailed models that estimate the loss of productivity from erosion will certainly be used in the next published USDA assessment of national soil resources scheduled for 1985 (NCR, 1984). However, likely no model will have been validated to the desired degree, and field data available by 2000 will likely not be conclusive. Yet, some consensus will almost necessarily be reached by 2000, and certainly it will be much more scientifically based than were decisions in the mid-1950's. However, the issue of the impact of erosion will likely be raised again, perhaps about year 2030. Careful thought needs to be given toward maintaining long-term field experiments to evaluate the long-term effect of erosion on productivity and to validate productivity models.

Most information learned on reclamation of soils will be used on reclaiming surface-mined land although more reclamation of severely eroded land will be attempted (House et al., 1984; Langdale, 1984). However, the significance and importance of managing and improving eroded land will depend on pressures to bring more land into production. Little attention is likely to be given to specific eroded areas in fields other than the practice of good soil management practices on the field as a whole. The eroded areas will benefit more from this application of technology than will the noneroded areas.

VI. POTENTIAL PRIMARY IMPACTS

The major potential impact of this technology on agriculture will be significantly improved erosion control with little loss, if not gain, in crop yield, improved water quality, improved farmability, increased profit, and other desirable features. In fact, this technology hopefully will provide farming systems with enough positive benefits so that erosion control becomes a side benefit. Should this be possible, reduced public support would be required to implement erosion control. Therefore, both the farmer and public will benefit from this technology.

In spite of improved erosion control, soil resources will still need to be inventoried. New technology will reduce the cost and time needed to accomplish this task, which will provide more and better information that can be more readily accessed. Agencies involved in these inventories will directly benefit. Inventory information has already and will continue to be used by those concerned with off-site problems associated with erosion including water quality and sedimentation problems. Furthermore, the data will be useful for other on-site management applications besides erosion control. Therefore, a broad spectrum of users will benefit from this technology.

Finally, this technology will provide a more scientific basis for the impact that man's activities are having on U.S. soils. This technology should allow more efficient use of this resource while adequately protecting it for future generations.

REFERENCES

1. American Society of Agricultural Engineers (ASAE), "Crop Production with Conservation in the 80's," St. Joseph, MI, 1981, 281 pp.

2. American Society of Agricultural Engineers (ASAE), "Erosion and Soil Productivity," St. Joseph, MI, 1985, 285 pp.

3. American Society of Civil Engineer (ASCE), Sedimentation Engineering, American Society of Civil Engineers, New York, NY, 1975, 745 pp.

4. Barrows, H.L., "Reclamation of surface-mined areas in the United States." In: Hill Lands, Proceedings of an International Symposium, West Virginia University, Morgantown, 1976, pp. 445-456.

5. Bartelli, L.J., "Soil development, deterioration, and regeneration." In: Proceedings of the Soil Transformation and Productivity Workshop, National Academy of Sciences/National Research Council, Washington, DC, Topic III, 1980 (unpublished).

6. Council for Agricultural Science and Technology (CAST), "Soil erosion: Its agricultural, environmental, and socioeconomic implications," Report No. 92, Ames, IA, 1982, 29 pp.

7. Crosson, P., "New perspectives on soil conservation policy," Journal of Soil and Water Conservation 39(4):222-225, 1984.

8. Doster, D.H., D.R. Griffith, J.V. Mannering, and S.D. Parsons, "Economic returns from alternative corn and soybean tillage systems in Indiana," Journal of Soil and Water Conservation 38(6):504-508, 1983.

9. Foster, G.R., J.M. Laflen, and C.V. Alonso, "A replacement for the USLE." In: Proceedings of the Natural Resources Modeling Symposium, ARS-30 USDA-Agricultural Research Service, Washington, DC, 1985a, pp. 468-472.

10. Foster, G.R., R.A. Young, M.J.M. Romkens, and C.A. Onstad, "Processes of soil erosion by water." In: Soil Erosion and Crop Productivity, Soil Science Society of America, Madison, WI, 1985b, pp. 137-162.

11. General Accounting Office (GAO), "Agriculture's Soil Conservation Programs Miss Full Potential in the Fight Against Soil Erosion," Report RCED-84-48, Washington, DC, 1983, 79 pp.

12. Hayes-Roth, F., D.A. Waterman, and D.B. Lenat, "Building Exert Systems," Addison-Wesley Publishing Company, Inc., Reading, MA, 1983, 444 pp.

13. House, G.J., B.R. Stinner, D.A. Crossley, E.P. Odum, and G.W. Langdale, "Nitrogen cycling in conventional and no-tillage agroecosystems in the Southern Piedmont," Journal of Soil and Water Conservation 39(3):194-200, 1984.

14. Korsching, P.F., C.W. Stofferahn, P.J. Nowak, and D.J. Wagener, "Adopter characteristics and adoption patterns of minimum tillage: Implications for soil conservations programs," Journal of Soil and Water Conservation 38(5):428-431, 1983.

15. Langdale, G.W., personal communications, USDA-Agricultural Research Service, Watkinsville, GA, 1984.

16. Larson, W.E., R.F. Holt, and C.W. Carlson, "Residues for soil conservation." In: Crop Residue Management System, American Society of Agronomy, Madison, WI, 1978, Chapter 1, pp. 1-15.

17. Larson, W.E., F.J. Pierce, and R.H. Dowdy, "The threat of soil erosion to long-term crop production," Science 219(4584):458-465, 1983.

18. Lee, L.K., "Land use and soil loss: A 1982 update," Journal of Soil and Water Conservation 39(4):226-228, 1984.

19. McCarl, B.A. and B.A.J. Pheasant, "Repfarm: Documentation of the computer model," Station Bulletin No. 409, Agricultural Experiment Station, Purdue University, W. Lafayette, IN, 1983.

20. Moldenhauer, W.C., G.W. Langdale, W. Frye, and others, "Conservation tillage for erosion control," Journal of Soil and Water Conservation 38(3):144-151, 1983.

21. National Research Council (NRC), personal communication, Workshop on the 1982 National Resources Inventory (NRI), July 1984, Washington, DC, 1984.

22. Perrens, S.J., G.R. Foster, and D.B. Beasley, "Erosion's effect on productivity along nonuniform slopes." In: Erosion and Soil Productivity, American Society of Agricultural Engineers, St. Joseph, MI, 1985, pp. 201-214.

23. Piest, R.F., L.A. Kramer, and H.G. Heinemann, "Sediment movement from loessial watersheds." In: Present and Prospective Technology for Predicting Sediment Yields and Sources, ARS-S-40, USDA-Agricultural Research Service, Washington, DC, 1975, pp. 130-141.

24. Pierce, F.J., W.E. Larson, R.H. Dowdy, and W.A.P. Graham, "Productivity of soils: assessing long-term changes due to erosion," Journal of Soil and Water Conservation 39(1):39-44, 1984.

25. Reuss, J.O. and R.E. Campbell, "Restoring productivity to leveled land," Soil Science Society of America Proceedings 25(4):302-304, 1961.

26. Riggins, R.E. and W.D. Goran, "Soils information systems: A data source for watershed management." In: Proceedings of the D. B. Simons Symposium on Erosion and Sedimentation, Colorado State University, Ft. Collins, 1983, pp. 5.39-5.47.

27. Schertz, D.L., "The basis for soil loss tolerances," Journal of Soil and Water Conservation 38(1):10-14, 1983.

28. Smith, D.D., D.M. Whit, A.W. Zingg, A.G. McCall, and F.G. Bell, Investigations in erosion control and reclamation of eroded Shelby and related soils at the Conservation Experiment Station, Bethany, Mo., 1930-42, Technical Bulletin No. 883, U.S. Department of Agriculture, Washington, DC, 1945, 175 pp.

29. Tollner, E.W., H.L. Hargrove, and G.W. Langdale, "Influence of conventional and no-till practices on soil physical properties in the Southern Piedmont," Journal of Soil and Water Conservation 39(1):73-76, 1984.

30. Trimble, S.W., "Man-induced soil erosion on the Southern Piedmont, 1700-1970," Soil Conservation Society of America, 1974, 180 pp.

31. Trimble, S.W., "The fallacy of stream equilibrium in contemporary denudation studies," American Journal of Science 277(Summer):876-887, 1977.

32. U.S. Department of Agriculture (USDA), "Soil, Water, and Related Resources in the United States: Status, Conditions, and Trends, 1980 Appraisal, Part I," Washington, DC, 1981a, 328 pp.

33. USDA-Agricultural Research Service, Report of the Soil Erosion Soil Productivity Research Planning Workshop, Washington, DC, 1981b.

34. USDA-National Soil Erosion-Soil Productivity Research Planning Committee (J.R. Williams, chairman), "Soil erosion effects on soil productivity: A research perspective," Journal of Soil and Water Conservation 36(2):82-90, 1981c.

35. USDA-Soil Conservation Service, 1984 Soil and Water Conservation Research and Education Progress and Needs, Washington, DC, 1984.

36. Van Doren, D.M., H.L. Barrows, O.P. Engelstad, and others, "Humid regions, conservation needs and technology on agricultural lands." In: Soil and Water Resources: Research Priorities for the Nation, Soil Science Society of America, Madison, WI, 1981, pp. 41-61.

37. Wade, J.C. and E.O. Heady, "Measurement of sediment control impacts on agriculture," Water Resources Research 14(1):1-8, 1978.

38. White, A.W., R.R. Bruce, A.W. Thomas, G.W. Langdale, and H.F. Perkins, "Effects of soil erosion on soybean yields and characteristics of Cecil-Pacolet soils," Research Report No. IRC 060184, Southern Piedmont Conservation Research Center, USDA-Agricultural Research Service, Watkinsville, GA, 1984, 36 pp.

39. Williams, J.R., K.G. Renard, and P.T. Dyke, "EPIC-A new method for assessing erosion's effect on soil productivity," Journal of Soil and Water Conservation 38(5):381-383, 1983.

40. Wischmeier, W.H., and D.D. Smith, Predicting Rainfall Erosion Losses, Agriculture Handbook No. 537, USDA-Science and Education Administration, 1978, 58 pp.

41. Woodruff, N.P. and F.H. Siddoway, "A wind erosion equation," Soil Science Society of America Proceedings 29:602-608, 1965.

Background Paper No. 18

Multiple Cropping

Charles A. Francis
University of Nebraska

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

MULTIPLE CROPPING

Summary

Multiple cropping is the intensive cultivation of more than one crop per year on the same land so as to use land, water, light, and nutrients efficiently. Double cropping, or the sequential planting of two crops, such as wheat in the winter and soybeans in the summer, is the only pattern commonly used in the United States. Intercropping, the simultaneous culture of two or more crops in the same field at the same time, is popular with low-resource farmers.

Although widely used in the lesser developed countries by farmers with limited land and resources, multiple cropping systems have not been extensively explored for their applications in this country. In addition to their efficient use of resources, intensive cropping systems offer several other benefits: vegetative cover through much of the year, which prevents erosion; the need for less fertilizer, owing to the contributions of legumes in these systems; and moderate to high potential yields that are sustainable over time.

Relatively little research attention has been paid to these systems in temperate agricultural regions. If such systems are to be widely adopted in the United States, major new technological advances may be necessary in four areas: breeding crops for intensive planting systems, understanding competition by plant species for growth factors, improving plant nutrition through fertilizers and microbiology, and developing mechanization for multiple cropping.

Crop breeding for multiple cropping systems can lead to development of crops that can endure the stress conditions found in multiple-species crop combinations. Varieties and hybrids already exist that are well adapted to

double cropping and reasonably well suited to relay cropping, the planting of two or more crops with an overlap of the significant part of the life cycle of each crop. Further refinement is needed in developing new hybrids and in further selecting for adaptation. Results could be available in 15 years.

The competition for growth factors by crops that are grown together or sequentially is not well understood. Such competition includes that between two plants of the same species, between two crops of different species, and between crops and weeds. Competition has been studied in grass/legume mixtures for pasture systems, and basic work on crop/weed competition gives insight on species interactions. Some of the results and much of the methodology can be applied to intercropping. Since existing varieties can be used for most preliminary work, results could be available in 6-10 years.

Multiple cropping entails a greater input of nutrients or an alternative approach to plant nutrition. Low-resource alternative cropping systems include rotations, minimum-tillage methods, and use of low levels of fertilizers that do not disturb the biological balance in the soil. Research on nitrogen fixation is an active area at present, but a basic understanding of plant nutrition could take 10-15 years to develop.

Machines already available can be used for planting and for most other cultural operations. Through modifications of existing tillage, planting, and cultivating equipment, the farmer can accomplish multiple cropping. However, the development of a combine that can harvest two crops simultaneously is necessary for intercropping to have widespread applications. This short-term objective could be achieved within 5 years, using expertise from the commercial sector.

The principal impacts from multiple cropping will be reduced production costs and increased output per year from a given unit of land. The greater sustainability of production and the reduction in energy use would lead to a more stable agricultural sector.

MULTIPLE CROPPING

I. Introduction

A. Definition and scope:

Multiple cropping describes a range of intensive patterns of crop cultivation which efficiently use land, light, water, and nutrients. These cropping systems are likely to become more important as methods of cultivation in the future. Broadly defined as the planting of more than one crop per year on the same land, multiple cropping has several variations which are well known to farmers in the traditional sector of developing country agriculture, but relatively unknown in the U.S. Double cropping, the planting of two crops in sequence during the same crop year, now occupies more than five million acres in the southeastern U.S. References to research in this field are presented at the end of the paper. Similar to this, relay cropping is the planting of two or more crops with an overlap of a significant part of the life cycles of two crops. Ratoon cropping is the culture of regrowth after the first harvest; sugar cane is a typical example of this system, and perennial forages could be called a ratoon type of culture. Since existing technology can be used successfully with most of these cropping patterns, little further mention is made of their importance or component technology. Intercropping is the simultaneous culture of two or more crops in the field at the same time. This may be intensive (both crops in the same row), or may be in alternate rows, or cultivated strips of each crop. It is this pattern which is popular with many low-resource farmers, but has not been researched in any meaningful detail.

Although widely practiced by small farmers with limited resources in LDC's, many of these options have not been explored in the U.S. Some of the advantages which these systems offer to the U.S. farmer include:

-- intensive exploitation of available light, rainfall, and nutrients

-- vegetative cover through much of the growing season to reduce erosion, especially with zero tillage techniques

-- potential for reduced use of energy-intensive inputs including fertilizer,when legumes and cereals are in the pattern

-- moderate to high potential yields, stable and sustainable over time, with reduced costs of production.

Additional advantages which are cited by farmers with limited resources as reasons why they use multiple cropping include:

-- high level of species diversity which contributes to a balanced diet

-- competitive control of weeds

-- reduced incidence of disease and insect attack

-- intensive and well-distributed use of labor through the year

-- distribution of income and food sources throughout the year in a tropical climate.

Multiple cropping patterns contribute a significant portion of food in the developing world. They are not widely practiced in the U.S. outside of the use of double cropping and intensive vegetable production where the growing season is long enough. In the future, improved multiple cropping systems of various types have potential for reducing production costs, alleviating current erosion problems, introducing biological and economic buffering into farming systems, and through all these results improve the stability and sustainability of yields and total production in our prime agricultural regions. References to research in this area include those by Andrews and Kassam (1976), Francis (1978, 1979), Lewis and Phillips (1976), and Willey (1979a, 1979b).

B. Major Lines of Research:

Multiple cropping has received limited attention in the international agricultural research centers, national research programs in the tropics, and U.S. universities and other research centers. Progress in these projects does not appear rapid enough to bring new technology to the farmer very quickly, and increased research emphasis is needed to explore the total potentials of intensive cropping systems. Four principal lines of research could lead to development of major new technologies which are relevant to the agricultural industry in this country and overseas to realize the potentials outlined above.

-- Breeding crops for intensive planting systems

Highly productive varieties and hybrids have been developed for monoculture systems. Some of these are useful for multiple cropping, but greater potential productivity can be realized by developing and testing crops specifically for intensive intercrop systems.

-- Understanding competition by plant species for growth factors

In order to design efficient and productive combinations of crop species, it is important to develop a basic understanding of how plants compete for growth resources, both intraspecific and interspecific competition.

-- Improving plant nutrition through fertilizers and microbiology

Research in the efficiency of nutrient use and stress tolerance, plus the in-depth evaluation of biological potentials for enhancing fertility, can lead to design of new systems which are less costly and more sustainable over time.

— Developing mechanization for multiple cropping

Harvesting equipment is needed for intensive intercropping systems; existing equipment is adaptable to double cropping with modifications, and to some relay cropping situations.

II. Current State of the Art

A. Breeding crops for intensive planting systems

Major advances have been made in variety and hybrid development for high technology monoculture cropping in the U.S. Equally impressive potentials have been created in rice, wheat, and other species which have contributed to the green revolution in the developing world. Not all of the advances from these efforts are applicable to intensive systems such as multiple cropping. Particularly in less developed countries, this technology has not reached subsistence farmers, nor are there varieties of all species which can do well in intercropping patterns. The best hybrids and varieties in the U.S. and new ones under development will not necessarily offer maximum potential for multiple crop systems.

Research on genotype by cropping system interaction shows that special breeding programs or testing schemes are needed in some species to select new varieties for these systems. Germplasm resources and genetic variability exist which can be used in selection, and plant breeding methodology used for monoculture crop improvement can be modified and adapted to do this research. A number of maturity types, height variations, and other physically different types exist in most crop species. At present there is limited research in progress in the U.S., and the best work is in the international crop research centers. Although plant improvement is a long-term process, specific breeding and selection objectives could be applied using available genetic variability to develop and test new germplasm and release commercial hybrids and varieties within 15 years.

B. Understanding Competition by Plant Species for Growth Factors

Basic research on the competitive ability of crop plants for growth factors is needed to better understand the relationships among plants growing in close proximity. This includes competition between two plants of the same species, between crops of different species, and between crops and weeds. Ecologists refer to this phenomenon as niche-space overlap. These relationships may be complementary in some instances. Mixing of species or intensification of cropping in the time dimension may change (and often reduce) the problems of competitive weed species. Basic data on plant interactions can be interpreted and translated into design of new varieties, cropping practices, and cultural management systems. Thus, the basic research leads directly to practical applications in the field. These can be tested on commercial farms, and successful multiple cropping (including double cropping and intercropping systems) introduced through publications and the extension service.

Competition has been studied in grass/legume mixtures for pasture systems. Basic work on crop/weed competition gives insight on species interactions. Some of the results and much of the methodology can be applied to intercropping. There is a considerable recent body of information from empirical agronomic trials which combine crop species, density. planting date, and spatial pattern variables. Some include crop yield components which give an indication of when stress occurred and how severe this was. Most lack the basic information needed to determine the spatial or temporal competition for light and moisture. Only limited research is in progress in this area, and much more activity is needed to meet the goal of understanding competition and complementarity, and from this to design new cropping patterns. Since existing varieties can be used for most preliminary work, results could be available in 6 to 10 years.

C. Improving Plant Nutrition through Fertilizers and Microbiology

The intensification of cropping in time and space requires either greater outside nutrient input or an alternative approach to plant nutrition. Sequences or mixtures of cereals and legumes can take advantage of biologically fixed or produced nitrogen, and may be able to make efficient use of growth factors in cropping systems. Low resource alternative cropping systems may include rotations, minimum tillage schemes which keep residues on the surface and prevent the loss of nutrients through erosion, and use of low levels of appropriate soil amendments which do not disturb the biological balance in the soil. A new commercial potential exists in developing nutrient sources which are compatible with low chemical input agriculture, and creative research in this area could lead to alternative, reduced fossil fuel input, sustainable production systems. New varieties or hybrids can be selected which are more efficient in their use of nitrogen and other growth factors.

There is more basic work in progress on plant nutrition and microbiology than in any of the other three areas, yet little of this currently is directed toward multiple cropping or intercropping. Development of new principles in low resource crop nutrition, use of crop residues and organic waste by-products, and studies in soil microbiology are receiving considerable attention. Many results will contribute to development of principles useful in multiple cropping. Existing literature on organic plant nutrition, zero and minimum tillage, rotations, and erosion control can be used to design prototype cropping systems for further testing. Development and testing of soil amendments which are compatible with low resource, multiple species, sustainable cropping systems can be an extension of existing work. The wide exploitation of this potential to reduce production costs and seek more stable productivity awaits design and validation of the new production technology. Initial results could be available in 10 to 15 years, although a strong basic understanding of these interactions and of the efficiency of nutrient uptake and use could take much longer.

D. Developing Mechanization for Multiple Cropping

Efficient systems exist for planting, cultivation, and harvest of crops in monoculture in the U.S. Planting of most multiple crops is possible with existing equipment. The same is true of cultivation, with some modifications. There has been direct use or adaptation of existing machinery for harvesting double cropped soybeans in a growing wheat crop, or for harvesting wheat where relay cropped soybeans are already in early growth. Although some adaptations may have been tried for harvesting two crops simultaneously, these have not been widely publicized. There is little incentive at present for companies to develop machines for intensive intercrop harvesting in the U.S. In most developing countries, these crops are harvested by hand with family labor. Thus, this researchable area initially is most important to the developed world where labor is expensive. Conceptually the simplest among these four research areas, this engineering question could be solved within five years. Implementation of research and successful introduction of intercropping would provide industry with the potential for a new product needed by most farmers who plant complex and intensive systems. This is a major short-term research goal for developed countries.

III. Major Breakthroughs Needed (with indication of needed levels of funding)

A. Breeding Crops for Intensive Planting Systems

Varieties and hybrids already exist which are well adapted to double cropping and reasonably well suited to relay cropping systems in the U.S. Further refinement in these cultivars requires attention to proper maturity, efficiency of water and nutrient use, and harvestability under a range of weather conditions. All these traits can be selected for under monoculture.

Two research activities are needed for each major crop to determine and then develop the full genetic potential for intercropping. First is a continuation of the study of variety by cropping system interaction to decide whether existing varieties developed in monoculture have adequate yield potential in an intercropping pattern for specific crops. If results are positive, no specific breeding activity is needed for that crop in the short run. If there is a significant interaction, then selection should begin for traits which will better adapt this crop to the competitive rigors of intercropping.

The major obstacle to increased research support and activity in this area is the lack of convincing evidence that different varieties and hybrids are needed for these intensive systems, and that there is a bright future for intercropping in the U.S. Several recent books, and other chapters and books to be published in the next year will help to bridge this information gap.

(Moderate funding level needed for research)

B. Understanding Competition by Plant Species for Growth Factors

Double cropping makes a sequential demand on growth factors, while intercropping provides an intensive competition. Some basic information exists from the field of ecology which relates natural community resource use to cropping systems. More relevant is the data on grass/legume mixtures for pastures which describes how two or more species compete for limited growth factors. The distribution of light in a crop canopy, and how this is shared by competing intercrop species, is the best studied relationship in multiple cropping; even this information is limited. Less is known about competition for water and nutrients.

The major obstacle to progress in this area is lack of funding and limited interest by researchers in the intercropping systems in the U.S. As more evidence accumulates and review publictions scheduled for 1984 become available, this interest is likely to increase rapidly. Two companion papers in this OTA study which have relevance to the efficiency of resource use under competition are those by Berry (Photosynthesis) and Liebhart and Harwood (Organic Farming). Further research will lead to design of more productive intercrop patterns.

(Substantial level of funding needed for research)

C. Improving Plant Nutrition through Fertilizers and Microbiology

When cropping is intensified, greater levels of fertility are required to produce more biomass and more commercial product. This may come from more efficient use of existing nutrients in the soil, from adding chemical fertilizers, from modifying the farming system to provide more fertility from biological sources, or from a combination of these factors. A number of technical papers in this OTA report deal in depth with different aspects of fertility: Liebhart and Harwood (Organic Farming), Fischer (Crop Residue and Animal Waste Utilization), Foster (Soil Erosion, Productivity, and Tillage), Davis (Production and Use of Chemical Fertilizers), and Alexander (Nitrogen Fixation). These papers have information related to new sources of fertility, greater efficiency of use, and increased sustainability of systems. Although most reference is made to monoculture, the principles listed are especially desirable for multiple cropping systems.

Increased biomass production and plant residue remaining after harvest or harvests, reduced erosion as a result of less tillage, increased cover and organic matter to break the impact of rainfall and retain more water in the soil, and potential increase in soil biological activity could all be consequences of the use of newly designed intensive cropping systems. Multiple cropping does not require all these components, but they all have potential to contribute to productivity, reduced costs of production, and sustainability over time. There is a need for commercial products which contribute to fertility in this type of system, without interfering with or suppressing the potentials to improve fertility through biological means.

(Substantial level of funding needed for research)

D. Developing Mechanization for Multiple Cropping

Existing equipment can be used (perhaps with minor modifications) to accomplish all operations in double cropping and most relay cropping patterns. For intercropping patterns, the strip cropping option can also be planted and cultivated with existing machines. Intensive intercropping patterns can be planted and cultivated with current machinery through modifications and careful handling, but harvest is a major obstacle. Technology exists to make appropriate combines for harvest, but there has been no demand to date. A short-term but intensive testing of alternative prototype machines could quickly lead to the right technology to accomplish harvest of intercrops. The McClure paper (Machinery and Mechanisation) deals with harvest of intercrops.

(Low level of funding needed for research)

IV. Institutional Arrangements

There is potential for research in all these areas by federal, state, or private industry organizations. However, there are historical interests and areas of competence which suggest that one group may have a comparative advantage over another to approach specific areas of research. Without suggesting exclusion of other groups, these are generalizations about where the work is likely to occur.

A. Variety and hybrid development will be a joint venture between public and private researchers. The basic genotype by cropping systems work logically will be accomplished by state and federal researchers, while the development of commercial varieties or hybrids will be a private venture for most cross-pollinated crops (commercial hybrids) and public activity for most self-pollinated crops (commercial varieties). Neither activity will be exclusive, and commercial seed companies are becoming increasingly active in the development and sale of self-pollinated crop varieties.

B. and C. Basic research on plant competition, fertility, and soil biology will most likely occur in the federal and state research organizations. Past work on the basic biology of competition and the practical applications of this work in agriculture has been concentrated in USDA and state agricultural research stations, and this is likely to continue. Practical work in soil fertility has often been a joint venture between private companies and public researchers, with private sector grants to public agencies to accomplish much of the research. Soil microbiology has been predominantly a public sector activity. Although these categories are not exclusive, they do reflect a historical pattern and likely future direction for this basic work.

D. Research on mechanization of harvest likely will occur in the private sector, where funding, facilities, and technical expertise exist for doing this job quickly and efficiently.

V. Likely Timing of Commercial Introduction

There is a potential for commercial application of new varieites or practical results as soon as they are available in developing countries. In the U.S., applications of new varieties or hybrids can be made immediatly if these are designed and selected for double cropping. These systems already exist, and are increasing in importance where growing season and rainfall are adequate for these extended season patterns. Use of varieties, competition data and subsequent new practices, and harvesting machinery can become commercial without the plant nutrition results if the farmer is willing to make a traditional N application. Lack of harvest technology is a practical constraint which could delay the entire adoption of intercropping unless the research questions are solved and the demand for combines makes their manufacture profitable. The entire package is in place for double cropping, and this practice is expected to spread. The package for intercropping could be used to realize sustainable production alternatives before the year 2000.

VI. Potential Primary Impacts

The likelihood of adoption of these several components of technology and of the entire package of practices varies with cropping pattern. Double cropping already is an accepted pattern in the southeastern U.S., and it is estimated that most of the increase in soybean and wheat acreage over the past decade in this region has been an increase in double cropping of these two crops. This trend will continue, and there is potential for a large increase in the overseeding of corn with nitrogen-fixing legumes late in the season. The likelihood of widespread application of this practice is about 90%, and it is already a recommendation in some states. The probability of wide use of intercropping is probably about 20%, and this will depend on solution of the several production constraints listed above.

The impact of these systems likely will occur with cereal/legume sequences or combinations because of the obvious complementarity in soil fertility. The wheat/soybean double crop has been mentioned, as well as the corn/leguminous covercrop combination. Other sequences and combinations are possible, but are less likely to receive attention in research because other crops are of lesser wide-spread importance. In the adoption profile, the rotations and reduced tillage schemes are likely to be scale neutral in use by farmers, while the use of intercropping requiring new combines for harvest may be restricted to large farmers with the resources to invest in this new and expensive technology.

The principle outputs of this research will be a reduction in costs of production as a result of less tillage, lower chemical nitrogen inputs, and more stable production due to better use of water and other natural growth factors.

There will be reduced erosion and thus greater sustainability to the systems. Finally, there will be a greater efficiency measured in crop output per unit of energy input into the crops. The technology for double cropping will be applied much as it is today, and this use will expand into more farms and new areas where moisture is adequate. Intercropping will require the entire package of information and practices, and if the combines are not available this is unlikely to be adopted at all.

Multiple cropping systems provide a generally untapped potential for increasing the sustainability of production and rationally using our production resources in this country. These systems have the potential for reducing production costs; for making better total use of light, water, and biologically produced nitrogen; for reducing soil erosion and consequent nutrient loss; for developing stable and sustainable production systems which can solve long-term food problems in this country and others in the developing world. It is imperative that these alternative multiple cropping systems be considered in the long-term projections for research to increase productivity in a sustainable U.S. agricultural sector.

VII. Literature Cited and Other References

Agricultural Research Service, USDA. 1977. Soil and water management systems for sloping land. ARS-S-160.

Andrews, D. J., and A. H. Kassam. 1976. Importance of multiple cropping in in creasing world foor supplies. In: Multiple Cropping , Papendick, R. I., et al., Amer. Soc. Agron. Spec. Publ. 27.

Banks, P. A., and R. R. Duncan. 1983. Weed-control evaluations in ratoon-cropped grain sorghum (Sorghum bicolor). Weed Sci. 31:254-258.

Banks, P. A., and J. S. Kvien. 1983. Weed control evaluations in no-till soybeans (Glycine max) double-cropped with rye (Secale cereale). Univ. Georgia Res. Rep. 431.

Boquet, D. J., and D. M. Walker. 1984. Wheat-soybean doublecropping: stubble management, tillage, row spacing, and irrigation. Louisiana Agr. Exp. Stn. Bull. No. 760.

Bryan, W. B., and M. B. Materu. 1984. Intercropping corn with climbing beans, cowpeas, and velvet beans. Crop Sci. (submitted)

Crookston, R. K., and D. S. Hill. 1979. Grain yields and land equivalent ratios from intercropping corn and soybeans in Minnesota. Agron. J. 71:41-44.

Duncan, R. R.(ed). 1981. Ratoon cropping of sorghum for grain in the Southeastern United States. Univ. Georgia Res. Bull 269.

Francis, C. A. 1978. Multiple cropping potentials of beans and maize. Hortscience 13:12-17.

Francis, C. A. 1979. Development of plant genotypes for multiple cropping systems. Ch. 7 in Plant Breeding Symposium II, K. J. Frey (ed). ISU Press.

Gallaher, R. N. 1975. Fertilization of double cropping and no-till systems: a review and a projection. Georgia Agr. Res. 17(1):14-20, 27.

Gallaher, R. N. 1975. Triple cropping in the Georgia piedmont. Georgia Agr. Res. 17(2):19-25.

Gallaher, R. N. 1977. Soil fertility management of double cropping systems. Dept. of Agronomy, Georgia Stn., Experiment, GA, Res. Rep. 248.

Gallaher, R. N. 1980. Potential and projection for increasing agronomic production with multiple cropping and/or minimum tillage systems in Florida. Multicropping Minimum Tillage Circular 479.

Gallaher, R. N. 1980. Multiple cropping minimum tillage. Florida MMT-1. (this series continues to date, with at least 20 titles in the series).

Gallaher, R. B., L. R. Nelson, and R. R. Bruce. 1976. Double cropping wheat and sorghum forage. Georgia Agr. Res. 17(4):9-12.

Hargrove, W. L. (ed). 1982. Proceedings of the minisymposium on legume cover crops for conservation tillage production systems. Univ. Georgia Spec. Publ. No. 19.

Hargrove, W. L., J. T. Reid, J. T. Touchton, and R. N. Gallaher. 1982. Influence of tillage practices on the fertility status of an acid soil double-cropped to wheat and soybeans. Agron. J. 74:684-687.

Langdale, G. W., A. P. Barnett, R. a. Leonard, and W. G. Fleming. 1979. Reduction of soil erosion by the no-till system in the Southern Piedmont. Trans. ASAE 22(1):82-86, 92.

Lewis, W. M., and J. A. Phillips. 1976. Double cropping in the Eastern United States. In: Multiple Cropping , Papendick, R. I. et al. (eds), Amer. Soc. Agron. Spec. Publ. 27.

Nelson, L. R., R. N. Gallaher, R. R. Bruce, and M. R. Holmes. 1977. Production of corn and sorghum grain in double-cropped systems. Agron. J. 69:41-45.

Nelson, L. R., F. M. Rouquette, Jr., and R. D. Randel. 1983. Cash wheat in a wheat-ryegrass grazing system. Texas Agr. Exp. Stn. B-1452.

North Carolina State Univ. 1981. No-till crop production systems in North Carolina -- corn, soybeans, sorghum, and forages. North Carolina Agr. Estension Service AG-273.

Sanford, J. O. 1979. Establishing wheat after soybeans in double-cropping. Agron. J. 71:109-112.

Sanford, J. O. 1982. Straw and tillage management practices in soybean-wheat double-cropping. Agron. J. 74:1032-1035.

Thomas, A. W., G. W. Langdale, and E. L. Robinson. 1982. Tillage and double cropped practices on watersheds. Proc. Conf. on Environmentally Sound Water and Soil Management, ASCE/Orlando, Florida.

Threadgill, E. D. (coordinator). 1981. Irrigated multiple-cropping production systems: a summary of progress for 1981. Univ. Georgia and USDA, Tifton, GA.

Touchton, J. T., and D. G. Cummins. 1978. Proceedings of the first annual

Southeastern no-till systems conference. Univ. Georgia Spec. Publ. No. 5.

Touchton, J. T., W. L. Hargrove, R. R. Sharpe, and F. C. Boswell. 1982. Soil Sci. Soc. Amer. J. 46:861-864.

Touchton, J. T., and J. W. Johnson. 1982. Soybean tillage and planting method effects on yield of double-cropped wheat and soybeans. Agron. J. 74:57-59.

Willey, R. W. 1979a. Intercropping - its importance and research needs. Part. I. Competition and yield advantages. Field Crop Abstr. 32:1-10.

Willey, R. W. 1979b. Intercropping - its importance and research needs. Part 2. Agronomy and research approaches. Field Crop Abstr. 32:73-85.

Background Paper No. 19

Present Status and Future Needs in Weed Control

C. G. McWhorter, W. C. Shaw, and E. E. Schweizer
Delta State Research Center
U.S. Department of Agriculture, Agricultural Research Center

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

WEED CONTROL
Summary

The cost of weeds to agricultural production is one of the most expensive factors in crop production, amounting to more than $20.2 billion annually. Losses caused by weeds include not only direct competition of weeds to reduce crop yields, but also reduced quality of produce, livestock losses, weed control costs, and increased costs of fertilizer, irrigation, harvesting, grain-drying, transportation, and storage.

Weeds can be defined as plants growing where they are not wanted. They range from trees and shrubs to grasses and even cultivated crop species. Volunteer corn, for example, is becoming an increasing problem in soybean production as more conservation tillage practices are being adopted.

In modern agriculture weeds are controlled through integration of crop competition, crop rotation, hand labor, and biological, mechanical, and chemical methods into integrated weed management systems (IWMS). Since 1950, the use of mechanical power for weed control has increased 30 percent, and herbicide use has increased sevenfold. However, manual labor has decreased 40 percent. As a result of modern weed control technology, farming is now less physical and more technological.

Although significant progress has been made in developing new weed control technology, weeds continue to cause severe reductions in yield and quality. Weeds often limit expanded use of conservation tillage and multicropping. New difficult-to-control weed problems develop through ecological shifts and because more established weeds develop increased tolerance to herbicides.

New weed control technologies needed include: (1) improved chemical and biological methods, (2) allelopathic chemicals to bioregulate weeds, (3) crop cultivars with improved tolerance to herbicides and the discovery of the nature of weed resistance to herbicides, and (4) the development of improved IWMS for conservation tillage and for annual multicrop production.

Development of selective herbicides has spearheaded the advances in weed control technology during the last 30 years and will continue to be important in the forseeable future. Major breakthroughs needed in this area include a nonselective chemical to control vegetation in fallow fields, more selective chemicals for control of broadleaved weeds in dicotyledonous crops (e.g., cotton, soybeans), and a chemical that can be applied postemergence for effective control of perennial weeds. There is also interest in control of weeds by bioagents, particularly with native pathogens like fungi.

The effectiveness of many herbicides is limited by soil activity; for example, some microbial populations rapidly degrade certain herbicides, limiting the residual effects of the herbicides. Advances in controlled-release technology could aid in this and other problems by reducing volatility and rates of application, reducing herbicide movement through the soil profile, increasing crop selectivity, and reducing environmental exposure. Also helpful is a class of chemical protectant that slows the action of soil microorganisms, permitting more cost-effective control.

Crops can be protected against the toxicity of certain herbicides through chemical antidotes called safeners, another class of plant protectant. When applied to seeds or soil, these chemicals make an otherwise susceptible plant species tolerant to an herbicide without affecting the weed control aspect of the herbicide.

Plants themselves release secondary chemicals during metabolism that can be toxic to other plants. Such allelopathic chemicals are being studied for their potential use in weed control.

Crops can be protected against the toxicity of certain herbicides through chemical antidotes called safeners, another class of plant protectant. When applied to seeds or soil, these chemical make an otherwise susceptible plant species tolerant to anherbicide without affecting the weed control aspect of the herbicide.

Plants themselves release secondary chemicals during metabolism that can be toxic to other plants. Such allelopathic chemicals are being studied for their potential use in weed control.

Developments in genetic engineering may allow the availability of herbicide-tolerant crop cultivars in agronomic crops in the next 10-15 years. Many weeds have evolved a tolarance to herbicides. The availability of herbicide-tolerant crop cultivars would permit the use of herbicides at higher rates to reduce the evolution of tolerance and would permit the use of herbicides that were previously nonselective.

Finally, research efforts need to be increased to develop more effective IWMS. Basic ecological research is needed to understand weed population dynamics, weed threshold levels, and shifts in weed populations caused by control technology. Research is also needed on how to use rotational tillage to aid in controlling the weeds that develop through several years of conservation tillage. Perennial weeds become particularly troublesome after only 2 to 3 years, and have forced many farmers to return to conventional tillage.

Improved weed control technology will result in a slow but steady decrease in production costs, and an estimated 10 percent increase in the cost of weed control. Increased use of conservation tillage will necessitate increased herbicide use in the next 2 decades.

PRESENT STATUS AND FUTURE NEEDS IN WEED CONTROL

BY

C. G. McWhorter, Ph.D; W. C. Shaw, Ph.D;
and E. E. Schweizer, Ph.D.

U.S.Department of Agriculture, Agricultural Research Service (USDA, ARS) Southern Weed Science Laboratory, Stoneville, MS; USDA, ARS, National Program Staff, Beltsville, MD; USDA, ARS Crops Research Laboratory, Ft. Collins, CO, respectively.

PRESENT STATUS AND FUTURE NEEDS IN WEED CONTROL

TABLE OF CONTENTS

Page

I. Protection of Agricultural Crops from Losses in Yield, Quality, and Increased Cost of Production Due to Weeds

A. Introduction to the Weed Control Problem and the Development of Weed Control Technology 5

B. Integrated Weed Management Systems, a Strategy for Concentrating Several Methods of Control to Improve Efficiency and Reduce Cost...................... 8

II. Major Lines of Weed Science Research Needed

A. Bioregulation of Weeds Through Use of Chemical and Biological Technology 10

B. Allelopathic Chemicals as Bioregulators for Weed Control 15

C. Improved Crop Tolerance and Increased Susceptibility of Weeds to Control Agents 16

D. Development of IWMS for Conservation Tillage and Annual Multicrop Production 18

III. Current State of the Art of Needed Technology

A. Bioregulation of Weeds Through the Use of Chemical and Biological Technology 20

B. Allelopathic Chemicals as Bioregulators for Weed Control 23

C. Improved Crop Tolerance and Increased Susceptibility of Weeds to Control Agents 24

D. Development of IWMS for Conservation Tillage and Annual Multicrop Production 25

IV. Institutional Arrangements

A. Bioregulation of Weeds Through the Use of Chemical and Biological Technology 27
B. Allelopathic Chemicals as Bioregulators for Weed Control 28
C. Improved Crop Tolerance and Increased Susceptibility of Weeds to Control Agents 28
D. Development of IWMS for Conservation Tillage and Annual Multicrop Production 29

V. Likely Timing of Commercial Introduction

A. Bioregulation of Weeds Through the Use of Chemical and Biological Technology 29
B. Allelopathic Chemicals as Bioregulators for Weed Control 30
C. Development of IWMS for Conservation Tillage and Annual Multicrop Production 30
VI. Potential Primary Impacts 30

I. Protection of Agricultural Crops from Losses in Yield, Quality and Increased Cost of Production Due to Weeds

A. Introduction to the Weed Control Problem and the Development of Weed Control Technology.

1. Definition of the problem. A weed is most frequently defined as a "plant out of place" or "a plant growing where it is not desired." In the United States, more than 1800 weed species cause serious economic losses each year. Cultivated crops are subject to competition from about 200 weeds. Each year, 10 to 50 different weed species infest all food, feed and fiber crops. Unlike other pests such as insects, diseases, and nematodes, weeds occur annually in all cultivated fields at plant populations that significantly reduce crop yields unless they are controlled.

Weeds include such undesirable plants as trees, shrubs, grasses, broadleaf plants, rushes, sedges, parasitic plants, aquatic plants, and even cultivated crop species. Volunteer corn, for example, is becoming an increasing problem in soybean production as conservation tillage practices are adopted. In this situation, corn not only reduces soybean yields, but it also reduces soybean seed quality and increases cost of production.

Weeds affect almost everyone and the cost of their control is one of the largest costs in crop production. Weeds and the cost of their control cost American agriculture more than $20.2 billion annually. Of this total, $13 billion results from a 10% annual loss in agricultural production. These losses result from the direct competition of weeds with crops for light, water, and nutrients and the effect weeds have on harvesting, grain-drying, transportation, and storage increased. About $3.1 billion were spent on herbicides in 1980, (Environmental Protection Agency, 1980) and because of inflation and increased usage of herbicides, 1984 expenditures on herbicides will be much higher. An additional $4.1 billion represents the cost of tillage and hand labor required for weed control each year.

2. Brief History of Weed Control in the United States Prior

About 5% of the weed technologies that we use today was developed before 1900 (Timmons, 1970), mostly between 1800 and 1900. During this period, mechanical developments were rapid, and included all-steel plows, wheel cultivators, springtooth harrows, riding cultivators, rotary hoes, and hand sprayers.

About 15% of the progress made in weed science technology occurred during the period 1901-1940 (Timmons, 1970), mostly in the use of mechanical equipment. These included rod weeders, tractor-mounted cultivators, blade and sweep cultivators, tractor-mounted sprayers, oil and LP gas flame burners, and granular spreaders.

The discovery of 2,4-D and related herbicides during the period 1942 to 1944 and the effectiveness of these herbicides for selective weed control provided the stimuli for the modern era of weed control. Many industrial manufacturers developed programs to discover, synthesize, and evaluate new herbicides that would control a broader spectrum of weeds and that would be more economical and safer to crops. The phenomenal discovery and production of new agricultural chemicals, mostly organic compounds, after 1950 led to widespread public use of important herbicides such as dalapon, MH, diuron, amitrole, naptalam, chlorpropham, DSMA, CDEC, EPTC, simazine, atrazine, 2,4-D, vernolate and many others during the 1950's (Timmons, 1970). Many of these are still in widespread use today.

Successes in the discovery and development of new herbicides were even more impressive in the 1960's, leading to usage of herbicides such as amiben, propanil, linuron, MSMA, picloram, trifluralin, fluometuron, and paraquat. The number of individual herbicides available in 1950 was about 25, as compared to about 75 by 1960 and 120 by 1969 (Timmons, 1970).

New herbicides continued to be discovered and introduced in the 1970's, but at a slower pace than during the previous decade. Some of the widely used herbicides introduced in the 1970's include metribuzin, glyphosate, metolachlor, alachlor, bentazon, sethoxydim, acifluorfen and norflurazon.

In 1949, herbicides were used on 23 million acres of agricultural land; in 1952 on 30 million acres; in 1959 on 53 million acres; in 1962 on 71 million acres; in 1965 on 120 million acres; and in 1980 on more than 250 million acres.

The production and use of herbicides have grown at a rate of about 7% a year since 1979. The domestic use of herbicides increased from 115 million pounds in 1963 to more than 800 million pounds in 1981. Currently, herbicides account for about 54% of the total pesticides used in the United States, and they represent about 60% of the value of total pesticide sales.

The progress made on biological methods of weed control from 1941 through the mid 1970's was extremely slow as compared to the development of chemical technology. However, interest in biological control increased in the mid 1970's, and has led to the development and commercialization of plant pathogens for control of northern jointvetch in rice and soybeans, and for stranglervine in citrus orchards.

Concurrent with the development of herbicides since the 1940's was the development of improved herbicide application equipment. After 1940, significant advancements were made in the development of granular applicators, nozzles and other spray equipment for use in both ground and aerial applications. Other advancements were made in low-volume spray equipment, mistblowers, flame cultivation equipment, controlled droplet applicators, the rope-wick applicator and equipment for applying herbicides as directed-postemergence sprays (underneath the crop canopy), and others. The availability of such a wide array of application equipment has increased the efficiency of pesticide application.

B. Integrated Weed Management Systems, a Strategy for Combining Several Methods of Control to Improve Efficiency and to Reduce Cost.

There are seven general methods of weed control: crop competition, crop rotation, biological, fire, mechanical, hand labor, and chemical. Usually the most efficacious and economical method of controlling weeds is a combination of two or more of these methods. Farmers have used combined methods for years, perhaps without realizing that they were utilizing integrated weed management systems (IWMS).

Crop competition is often one of the most economical weed control methods. Adequate stands of most crops can drastically reduce the development of many weeds. Also, some crop cultivars are more competitive to weeds than others.

Rotation of crops is often an efficient way to minimize weed competition. The best rotations for weed control usually include highly competitive crops such as summer row crops, winter grain or spring grain. The rotation of crops also permits herbicide rotations and this is becoming increasingly important in developing more effective IWMS.

Historically, biological control has worked best on large infestations of a single weed species. Also, biological control has been most successful where a weed was introduced into a new area and freed from its natural insect and disease enemies. Biological weed control has not developed to the point that it has had much overall impact on the production of agronomic crops.

Fire has been used for many decades to control weeds in forests, on ditchbanks, on roadsides, other non-crop areas, and in alfalfa and cotton. Flame cultivation is rarely used today.

Cultivation is still a highly important component of IWMS in most crops. The method by which crops have been produced in the United States has been dictated by the need for cultivation. The spacing of rows 30-40 inches apart in most row crops was fixed by the need to till the soil for weed control. There has been emphasis in recent years to reduce the number of cultivations to not only conserve energy, but to control soil erosion. There are many advantages of reducing tillage in crop production systems, but conservation tillage will not become the 'conventional method' of crop production in most geographical regions until effective weed control programs are provided.

Hand labor was a conventional method of weed control in most row crops in the United States until the 1950's. A drastic reduction in the use of unskilled labor to hoe weeds in row crops during the last 30 years has occurred as the farm work force decreased and the price of hoe labor greatly increased. It is unlikely that hoeing will be a major component of future weed control programs in row crops.

Development of selective herbicides has spearheaded the advances in weed control technology during the last 30 years. Twenty to 30 individual herbicidal treatments have been registered for each major crop in the United States. The array of selective herbicides offers farmers a wide choice of chemicals for control of the broad spectrum of weeds that are usually present. Herbicides will continue to be a key component in most IWMS in the foreseeable future.

In the United States, weed control in most crops is presently accomplished by employing or using IWMS to judiciously integrate methods of hand, mechanical, and chemical control, crop and herbicide rotation, and crop competition. IWMS has greatly reduced the labor and equipment requirements in crop and livestock production. Production also is less dependent on manual labor. The yields and quality of crops have increased and losses caused by weeds have been reduced from 20% to about 10%.

II. Major Lines of Weed Science Research and Breakthroughs Needed

A. Bioregulation of Weeds Through Use of Chemical and Biological Technology.

1. Herbicides. Herbicides have been an essential element of economical farm production for the past 30 years and their importance will continue into the foreseeable future. Although significant progress has been made in the development of herbicides, weeds continue to reduce quality and yield of crops because there is an almost endless reservoir of

weed seeds in soil for weed reinfestation. In addition, ecological shifts in the weed spectrum occurs because of changes in production technology that include the use of cropping sequences and rotations, cultivation, chemical, and other non-chemical methods of weed control. These ecological shifts provide the impetus for the need to continue weed science research to develop new herbicides and related technology. Even where the most advanced weed control technology is used, there are still serious weed problems that remain unsolved in the production of many crops.

Major breakthroughs in herbicide chemistry that are needed include: (a) a non-selective chemical to control vegetation in fallow fields. This chemical needs to be systemic, have little or no residual soil activity, is safe to all components of the environment, provide maximum control within one to three days, and one that can be applied by farmers at a cost not exceeding $8/acre; (b) more selective chemicals for control of broadleaf weeds that can be applied postemergence over-the-top in dicotyledonous crops (e.g., cotton, soybeans, peanuts, sugarbeets) at a cost not exceeding $8 to $10/acre; and (c) a chemical that can be applied postemergence for more effective control of perennial weeds, such as trumpetcreeper, redvine, milkweeds, horsenettles, and nutsedges. This chemical needs to translocate in sufficient amounts to provide excellent control within a day of its application, with little or no residual soil activity.

A wide variety of other types of herbicides would be highly beneficial, including herbicides applied preemergence to the soil surface with controlled-release characteristics, but the three classes mentioned above would be most beneficial at the present time.

2. Biological Control. Biological control is one of several components that must be considered for use with IWMS. Until recently, comparatively little research effort has been devoted to this area of control. The impetus to the increased interest in biological research has probably resulted from the successful commercialization of a pathogen (with the commercial tradename Collego) for the control of northern jointvetch in rice and soybeans, and another pathogen (the commercial product Devine) for control of stranglervine in citrus orchards. Probably the greatest chance for successful control of weeds with bioagents is with native pathogens, especially fungi.

Another breakthrough needed in biological weed control is an intensive survey of all plant pathogens that will control weeds effectively when applied at a predetermined level of infestation, along with estimates of their production potential. Perhaps the primary problem that may limit further advances in biological weed control with pathogens is the need for discovery and identification of a large number of pathogens that occur in nature with the limited scientific effort available.

3. Chemicals as Plant- and Herbicide-Protectants. Crops can be protected against the toxic action of some herbicides through the use of chemicals which serve as antidotes to the herbicide. These chemicals have been referred to as safeners, plant-protectants, herbicide antidotes, or contratoxicants. These chemicals, when applied to seeds or incorporated in soil, make an otherwise susceptible plant species tolerant to an individual herbicide without affecting the action of the herbicide against unprotected-susceptible plants. The three principal chemicals used as protectants to date include flurazole, dichlormid, and cyometrinil.

The mode of action of these protectants is unknown, but discovery of the mode of action would provide the impetus needed to develop protectants for many other herbicides which have little or no crop selectivity. This would also permit vastly expanded use of many older herbicides which are highly cost-effective and safe to the environment.

Another class of protectants protect certain soil-applied herbicides from rapid degradation by enzymes that are secreted by soil microorganisms. The soil persistence of carbamate herbicides (e.g., chlorpropham and propham) is often too short for satisfactory weed control; but the use of herbicide-protectants, such as dietholate and mephenate, slow the action of soil microorganism to degrade these herbicides, thus permitting more cost-effective control. The commercial availability of even better herbicide-protectants or extenders for a wide variety of herbicide chemistries will have a significant impact not only on herbicides that are used by farmers but also on the cost of weed control on a long-range basis.

The primary breakthrough needed with plant-protectants, in addition to new materials, is to discover their mode of action. Although discovery of other classes of compounds is also needed that will serve as plant- and herbicide-protectants, especially for use with crops that are highly sensitive to specific herbicides.

4. Controlled-Release Technology for Formulated Herbicides. The effectiveness of many herbicides is limited by inadequate soil residual activity. Research effort needs to be increased considerably to develop herbicides or formulations with controlled-

release characteristics. Recent discoveries in this technology, that utilize encapsulation, polymerized herbicides, copolymers, crop-seed coatings, and related formulation techniques, suggests that this is a highly profitable area for future research. Advances in controlled-release technology could result in reduced rates of application, reduced volatility, reduced herbicide movement through the soil profile, increased crop selectivity, and reduced environmental exposure.

Herbicides are frequently lost to the environment too quickly because of leaching and runoff. Furthermore, some microbial populations rapidly degrade certain herbicides and this reduces residual control. These problems could be minimized with successful development of controlled-release technology.

The major breakthrough needed for this technology to be successful is defining the chemical and physical factors that are involved in totally deactivating the herbicide initially, and then subsequently releasing the herbicide in soil at a predetermined and controllable level.

5. Improved Application Equipment. Improvements in the design and efficiency of herbicide application equipment has not changed appreciably since the introduction of 2,4-D in the 1940's. Innovative research is badly needed to develop advanced technology that can be used to apply chemicals and biocontrol agents more economically, more efficiently, and with greater safety to crops and to the environment.

Technology needs to be developed for the application of weed control agents in low volumes and ultra-low volumes of water, oils, and other diluents. Controlled-droplet applicators, spinning-disc sprayers, and electrostatic sprayers have offered promise in this area, but further improvements are needed to assure uniform application, permit widespread and effective usage. Sprayer equipment is needed to apply chemicals in a variety of liquid diluents and provide even distribution of uniform-sized droplets. This equipment should be economical, suitable for use on level and rolling terrain, capable of spraying diluents over a varying level of low volumes (0.1 to 5 gpa) and spraying chemicals at very low rates (2 ozs. or less per acre). It should also have low energy requirements, adjustable swath widths, and accurately gauge the dose of herbicide being applied.

B. Allelopathic Chemicals as Bioregulators for Weed Control.

Plants release many chemicals into the environment that are secondary in nature as opposed to the more primary compounds such as carbohydrates and proteins. Some of these secondary chemicals, called allelopathics, may cause direct or indirect effects, that are harmful or beneficial to plants or pests that effect plants. In theory, many of these allelopathics have a promising future as indicated by an increased amount of research during the last decade. For example, researchers have shown that crop residues can release toxic compounds that inhibit growth of plants or crop plants can secrete weed-controlling allelopathics. These examples offer a limited glance at the future kind of breakthroughs that are possible in research.

Allelopathics may play a major role in the development of new methods for the control of not only weeds, but insects, plant diseases, and nematodes. In 1977, an allelopathy research planning conference, comprised of national leaders in this area, concluded that indepth research into allelopathy could increase the total production of U.S. agriculture by 2% or about $2 billion annually (McWhorter, Thompson, and Hauser, 1977).

Expanded research on allelopathy will lead to improved weed control technology. The use of these naturally occurring products should be exploited in several areas of pest control.

C. Improved Crop Tolerance and Increased Susceptibility of Weeds to Control Agents.

Herbicides control weeds in cultivated crops because they kill or control them at rates lower than those that cause significant crop injury. Even though there are many herbicides available for weed control in most crops, there are still too many weeds that are either resistant to herbicides or it is too expensive to control them. This problem increases because changes in weed populations occur that are caused by the selective pressure of the herbicides themselves. The continuous use of herbicides often increases and magnifies the weed control problem because (a) inherently tolerant weed species increase in their level of infestation and spread, and (b) some originally susceptible weed species, through evolution, become tolerant.

The evolution of weeds tolerant to herbicides is closely related to the need for developing herbicide-tolerant crop cultivars. The availability of herbicide-tolerant crop cultivars would permit the use of herbicides at higher rates to reduce the evolution of tolerance within susceptible weed species. It also would permit the use of herbicides that were previously nonselective.

Many scientists believe that the development of herbicide-tolerant crop cultivars is not only possible but that it would greatly simplify many existing weed control problems and lead to greatly improved IWMS. Some scientists feel that development of herbicide-tolerant cultivars would be more efficient and economical than constantly seeking new herbicides to control unmanageable weed problems where the continuous use of herbicides has been practiced.

Herbicide-tolerant crop cultivars can be developed through conventional breeding and through use of more modern technology of genetic engineering including single cell and tissue cultures. The research efforts to develop herbicide-tolerant crop cultures have been increased within the last few years, but most of this research is done by industry, is kept confidential, and is not reported to the public.

The problem of weeds developing resistance to herbicides has increased during the last five years but the nature of herbicide resistance has not been identified. The first report of triazine-resistant weeds was published in 1970, and by 1983 the list of herbicide-resistant weeds included at least 24 genera and 37 species of weeds, located in at least 25 states, 4 provinces of Canada, and 10 other countries. The list is expanding every year (LeBaron, 1983). Herbicide resistance also has been identified for other herbicides including 2,4-D, dinitroanilines (e.g., trifluralin), paraquat, and the ureas (e.g., diuron) (LeBaron and Gressel, 1982).

Discovery of the mechanisms that cause increased tolerance of weeds to herbicides will be highly beneficial to weed science and to other disciplines. LeBaron and Gressel (1982) concluded that "special effort should be made to identify resistant biotypes which have superior germination, growth rate, photosynthetic efficiency, or other advantages.

Subsequent research effort to transfer herbicide resistance from weeds to crops should then concentrate on using germplasm also having these desirable characteristics."

D. Develop IWMS for Conservation Tillage and for Annual Multicrop Production.

Research efforts need to be increased to develop more effective IWMS (McWhorter and Shaw, 1982). Integrated weed control is a multidisciplinary, ecological approach to the management of weed populations. The approach utilizes a variety of control tactics singularly but within a single coordinated weed management system. In operation, IWMS encourages the fullest use of natural control factors complemented, as necessary, by artificial means of weed management. Integrated weed control brings different components together in a coordinated effort to limit the impact of weeds on crop production.

Increased research is needed to strengthen all of the components of IWMS. The need for improved chemical and biological technology, allelopathic chemicals, and improved crop cultivars have been discussed earlier. Other areas where research needs to be increased include: (a) the development of more efficient crop rotations that are more competitive to weeds, (b) more information on all factors that provide differential selective stress on weeds (narrow rows, dense cropstands, more intense shade from the crop canopy, differential fertility placement, differential use of herbicides, insects, pathogens, and cultivation, (c) information on the use of selective herbicide mixtures and mixtures of herbicides with other pesticides because antagonism in tank mixtures is becoming increasingly troublesome, (d) more information to define optimum rotations of tillage and of selected herbicides when used on the same crop and when used in crop rotation.

Presently there is little basic ecological research underway that helps us to better understand weed population dynamics, weed threshold levels, and shifts in weed populations caused by chemical and non-chemical control technology. Weed control tactics, based on threshold levels of weeds, have been determined for several individual weeds, but this information is needed for many weed species, and especially on weed populations comprising several different weed species. Essentially no information exists on the competitive effects of mixed populations of weed species on yield and quality of even the major crops. This information is needed to determine when herbicide treatments should or should not be applied.

Selective stress to weeds is a new concept that involves all factors that affect weed growth and these have not been researched collectively. Selective stress will concentrate all external forces to reduce weed competition, including the biological, mechanical, and chemical forces mentioned earlier.

Comparatively little is known about factors that affect weed seed germination. The development of weed seed germination stimulants or inhibitors could significantly improve weed management technology by forcing weed seeds to germinate uniformly or preventing weed seed from germinating at all.

Research is needed on the use of rotational tillage in conservation tillage. The continuous use of various types of conservation tillage may be limited in some crops and in some geographical areas because it will not be possible to economically control certain weeds after several years of conservation tillage. Consideration needs to be given to using tillage to aid in controlling weeds after several years of conservation tillage. The use of rotational tillage will aid in the efficient use of conservation tillage in many areas, but essentially no research has been conducted to define the frequency or best type of tillage needed when weeds become highly expensive or impossible to control with existing chemical technology.

The development of application of herbicides in diluents at low and ultra-low volumes is in its infancy. Research needs to be increased in this area to increase efficiency of application and to reduce application costs. Diluents other than water need to be considered in this research because scientists reported recently that crop oils (e.g., soybean oil) are more efficient than water and their use as diluents might permit reducing herbicide rates (American Soybean Association, 1984).

III. Current State of the Art of Needed Technology

A. Bioregulation of Weeds through the Use of Chemical and Biological Technology.

1. Herbicides. Patent applications on new herbicide chemistries are being filed at a steady rate of several hundred per year. Only a small percentage of these herbicides will eventually be marketed, but Industry is committed to discovering and developing new herbicides for the next several years. To increase their efforts in this area, Industry is expanding the size and scope of their basic research facilities. Several new herbicide

chemistries have recently been patented and the future development of these products could have a significant effect on crop production.

A recent report showed that 40% more energy, in the form of herbicides, was needed for no-till production in corn than for conventional tillage (Council for Agricultural Science and Technology, 1984). The acreage devoted to conservation tillage more than doubled from 1972 until 1981. There are major advantages to reduced tillage programs, such as reduced erosion, moisture conservation, and reduced fuel, labor and equipment cost, but a major disadvantage is increased use of herbicides. We estimate that the use of conservation tillage on over 200 million acres by the year 2000 will result in an increased use of herbicides of at least 40% per year. If this occurs, it will be necessary for industry to greatly increase herbicide production capability.

2. Biological. Compared to the total effort devoted to the development of herbicides, the total effort devoted to the development of biological methods of weed control is minuscule. ARS of USDA has about 10 scientists (SY) who conduct research to use insects to control weeds and about 9 SY to utilize plant pathogens for weed control. The State Agricultural Experiment Stations devote about 3 and 10 SY to develop insects and plant pathogens, respectively.

There are probably eight industrial organizations that are developing biological weed control technology, but only three or four of these organizations are actively involved in research on discovery and development of plant pathogens and insects. The total effort devoted to the development of biological weed control technology by State and Federal agencies and Industry is probably less than 1% of the total effort devoted to the discovery and development of new herbicides.

As discussed earlier, two commercial biocontrol agents are now marketed and one or two others might be marketed within the next few years. The level of marketing success achieved with these biocontrol agents will have a significant impact on the redirection of resources into biological weed control research during the next decade.

3. Chemical-plant protectants and herbicide-protectants. Industry is actively involved in research to identify additional plant-protectants and herbicide-protectants, although the extent of industry's involvement is unknown. Applications for new patents occur on an infrequent basis in the patent literature, and a major effort to discover these chemicals is probably restricted to less than 10 industries. The total effort devoted to this line of research in Federal, State, and private institutions is less than 5 SY annually. It is unlikely that the nation's research effort to discover plant- and herbicide-protectants will increase unless new, highly effective chemistries are discovered, or unless there is a major breakthrough to identify the mode of action of plant-protectants.

4. Control-release formulations. The development of controlled-release herbicide technology (encapsulation, polymerized herbicides, copolymers, crop seed coatings, etc.) is in its infancy. Limited research was conducted about 20 years ago on encapsulation of herbicides, but the formulations were prohibitively expensive. More recently, research by ARS-USDA showed that starch xanthate and sodium alginate performed well as the base for controlled-release formulations, but this technology has not been adopted. Other research in ARS-USDA has demonstrated that it is possible to apply herbicides as coatings to crop seeds to control weeds after the crop seeds are planted. Industry is conducting further research

on this principle, but we know of only one herbicide to be used in this manner.

We estimate that there are no more than 15 scientists involved in this type research in Federal, State, and private institutions. The number of scientists involved in research on controlled-release formulations in Industry is unknown, but this effort would also be less than 10 SY. We are not aware of any anticipated expanded research in this area.

5. Develop improved application equipment. Most of the improvements in herbicide application technology developed between 1950 and 1970 was by agricultural engineers in ARS-USDA, the equipment industry, and by the two groups working together. Since 1970, most innovations have come from weed scientists (the rope-wick applicator, the recirculating sprayer, and sub-surface applicators), from small equipment manufacturers (the CDA sprayer by Micron West), or from the pesticide industry (the Electrodyn sprayer from ICI). We know of no increased research efforts directed toward improving herbicide application technology.

We estimate that there are less than 30 scientists in Federal, State, and private institutions working to improve application technology. There are probably an equivalent number in the pesticide industry, including both large and small equipment manufacturers. Steady progress has been made in this area, but we envision no dramatic changes in research efforts to improve spray technology within the foreseeable future.

B. Allelopathic Chemicals as Bioregulators for Weed Control.

The research effort on allelopathy in Federal, State, and private institutions probably does not exceed 12 SY annually.

Inputs from Industry are small. Steady advances have been made, but progress is slow. An extensive summary of recent progress was edited by Miyamoto, Kearney, and Takahashi (1983). Several allelopathic compounds described in this book appear highly promising for plant growth regulation. One of these, bialaphos, is chemically related to glyphosate (Roundup, from Monsanto) and is being actively investigated as an herbicide. Bialaphos, and several other naturally occurring products, will likely be developed by industry, but progress in this field will probably be slow because less than 20 scientists are employed by industry to conduct research with allelopathics in the United States.

C. Improved Crop Tolerance and Increased Susceptibility of Weeds to Control Agents.

Plant breeders in both public institutions and private industry have traditionally devoted little effort to breeding cultivars with increased herbicide tolerance. Probably no more than 15 plant breeders have been involved in this research and most of them devoted only a small fraction of their time to breeding for increased herbicide tolerance. In recent years, however, plant breeding has become more sophisticated and specialized. Private industry has increasingly taken over varietal development and Federal and State plant breeders now find their role as one of providing germplasm for use by industry. This trend will likely continue, with public research being devoted primarily to identifying germplasm with better herbicide tolerance. In 1984, however, the total amount of research devoted to this effort was relatively small.

Developments in genetic engineering have been rapid in recent years. Much of this effort is related to the development of germplasm with increased herbicide tolerance. There are probably about 15 scientists in Federal, State, and private institutions who are devoting at least some of their effort to increasing crop tolerance to herbicides. There are probably about 100 scientists in small private companies and with Industry who are working to provide increased herbicide tolerance in a number of crops. Most of this research is kept confidential, but it appears that progress is being made to identify genes with increased tolerance and to incorporate these into acceptable cultivars.

We predict that increased herbicide tolerance will be commercially available in selected horticultural crops within the next five to six years. Considerable time will be required to accomplish the transfer of tolerance to agronomic crops, so 10 to 15 years may be required before significant progress is evident.

D. Develop IWMS for Conservation Tillage and for Annual Multicrop Production. Significant progress has been made in the last 20 years in the development of more effective IWMS, but weeds continue to cause severe reductions in crop yield and quality. With changes in production technology, such as the use of different cropping sequences, rotations, and continuous use of the same chemicals, ecological shifts in the weed spectrum are likely. Even with the most effective weed control methods available, there are still many serious weed problems that remain unsolved in the production of individual crops.

Nearly 200 herbicides are registered for use in the United States, and several herbicides are available for use in most crops. Even so, the cost of control is still high and this needs to be reduced. Full-season weed control programs are costly, e.g., soybeans \$30/acre (\$74 per/ha), peanuts \$70/acre (\$168/ha).

Other components of IWMS have been improved, including more efficient rotations and cropping sequences, more competitive crop cultivars, more efficient methods of herbicide application, and improved knowledge of tillage practices on the basic biology of weeds. Even so, the pressure exerted by weeds in crop production remains relatively constant with conventional tillage, but increases dramatically after a few years of conservation tillage. Perennial weeds are particularly troublesome after only two or three years of conservation tillage, and these weeds have forced many farmers to return to conventional tillage. Weeds and the cost of their control still total about 10% of the total value of all crop production in the United States. We feel that these losses will continue with conventional tillage, and will increase with conservation tillage, until new and improved technology is developed.

Progress in many areas of weed science has been slow because the total research effort in State and Federal agencies never exceeded 200 SY/year until 1977. In 1982, only 264 SY were devoted to weed science research, but these are distributed throughout nearly 30 fields of science as defined by the Current Research Information (CRIS) of the USDA. Thus, the total scientific effort in many 'fields of science' is only 1-5 SY and these are usually located in different institutions. In 1980, it was reported that less than 10% of the State and Federal research effort on pest control (insects, pathogens nematodes, and weeds) was directed to the control of weeds (Bertrand, 1980).

IV. Institutional Arrangements.

A. Bioregulation of Weeds Through the Use of Chemical and Biological Technology.

Industry will continue to provide the major inputs into the development of chemicals, herbicide-crop protectants and herbicide-chemical protectants. Development of a new chemical, including synthesis, primary, secondary, and final evaluation, and registration requires $10-20 million and vast amounts of scientific efforts over a period of 7 to 10 years. About 80% of this input is by industry, 15% by State agencies, and 5% by Federal agencies.

Fryer (1982) estimated that about 738 scientists are involved in herbicide development in Industry in the United States. About 199 devote full time to herbicide development, 210 devote at least 50% of their time, and 329 devote less than 50% of their time. This would probably represent about 400 SY each year.

An estimated 35% of the national effort to develop biological methods of control during the last 10 years has been by Federal scientists, 45% by State scientists, 10% by scientists at private universities or in small business, and 10% by the U.S. pesticide industry. We believe that the role of Industry will increase sharply, with as much as 50 to 70% of the total effort on biological control conducted by Industry within 15 years. Until then, State and Federal scientists will continue to play a major role in identifying biological technology.

Federal and State scientists have probably provided more than half of the new innovations and developments in herbicide application technology during the last 15 years. They will continue to discover and develop new technology, although final development and sales will be by small business and large equipment manufacturers.

B. Allelopathic Chemicals as Bioregulators for Weed Control.

Private, State, and Federal agencies probably devote no more than 12 SY each year to allelopathy research and the involvement of the U.S. pesticide industry does not exceed this level. Future increases in allelopathy research by Industry will depend on major breakthroughs that identify promising chemistry. If promising chemistries are forthcoming within the next two decades, we estimate that 70% of the total effort devoted to allelopathy research would be by industry, 15% by Federal agencies, 10% by State agencies, and 5% by private agencies.

C. Improved Crop Tolerance and Increased Susceptibility of Weeds to Control Agents.

Until 1980, more than 95% of the effort devoted to produce crop cultivars resistant to herbicides was by State and Federal scientists. This combined effort probably has not exceeded 2 SY/year.

As new techniques are developed in this area of technology, and additional breakthroughs occur, both large and small private businesses will continue to assume a larger share of this research effort. The first crop cultivars developed specifically for increased tolerance to herbicides will probably be introduced to farmers within six to seven years, but the development of agronomically acceptable crop cultivars will likely require 15 to 20 years. The overall role of Federal scientists will continue to be comparatively small, probably less than 10 SY per year. The effort devoted by State agencies may ultimately reach 30 to 35 SY during the next 15 years, so it will be necessary for private business to make major inputs into this promising field.

D. Develop IWMS for Conservation Tillage and for Annual Multicrop Production.

About 30 Federal SY, 60 State SY and 100 industrial SY are presently devoted to the development of improved IWMS. Increases in the effort devoted to developing IWMS will increase steadily during the next 15 years, although the increases will be slow. Increases may be as large as 25 to 30% by State and Federal agencies, but the increased effort by Industry will probably not exceed 10%.

V. Likely Timing of Commercial Introduction.

A. Bioregulation of Weeds Through the Use of Chemical and Biological Technology.

We believe that new herbicides will continue to be provided to the farmer at the present rate of about one per year. New herbicides will initially be used in only one or two crops and expanded registration of most selective herbicides will continue for 15 to 20 years. This, combined with the six- to seven-year period between synthesis and the first registration, implies that a highly selective herbicide discovered in 1984 would first be registered for commercial sales in 1991 to 1994, and its ultimate registration on 20-30 other crops would occur from about 1996 to the year 2016.

Two new biological weed control agents might be introduced to farmers by as early as 1988. It is unlikely that other biological weed control agents would be introduced before 1990. The economic impact of these will probably be less than the commercial sales of an equal number of new herbicides.

The commercial introduction of new crop-protectants and herbicide-protectants is highly speculative and, to a large extent, depends on a major breakthrough. Perhaps two or three chemicals of these types could be introduced within the next 16 years with the present level of research devoted to this area. Research on the development of controlled-release formulations of herbicides is slow and steady, and we are not aware of recent major breakthroughs.

New herbicide application technology continues to become available at a slow rate. We are not aware of any recent breakthroughs that have not already been introduced commercially. We expect the steady development of this technology to continue.

B. Allelopathic Chemicals as Bioregulators for Weed Control.

At the present level of research, there will be very little commercial introduction of this technology by the year 2000. Perhaps two or three naturally occurring chemicals could be marketed as herbicides by the year 2000, but the economic impact of these will probably be no greater than an equal number of new herbicides.

C. Development of IWMS for Conservation Tillage and for Annual Multicrop Production.

We project slow, steady gains in the development of more efficient IWMS. We believe that significant advances will occur in different components of IWMS, but dramatic changes in existing technology will be dependent upon major breakthroughs discussed under A, B, and C.

VI. Potential Primary Impacts.

At the present rate of development of weed science technology, we estimate that the annual benefits and other effects by the year 2000 will include: (a) a reduction from 10 to 7% in crop losses, or a savings of $6.9 billion (US 1984 dollars); (b) a 10% increase in the cost of weed control, at a cost of $1 billion; (c) a 2% improvement in the quality of crops and fewer livestock deaths, for a savings of nearly $2 billion; (d) a 5% increase in crop production and crop efficiency, for a savings of about $2.5 billion; and (e) an annual reduction in gasoline and diesel fuel requirements from 8 billion to 3 billion gallons achieved through reduced tillage, for a savings of $5 billion. All of the above projections represent a slow and steady increase in savings as a result of improved weed control technology, with the exception of the cost of weed control. Increased use of conservation tillage, and especially no-till, will result in much greater herbicide usage. This will result in significant savings in tractor fuel, but this will only partially offset the increased cost of herbicides and the increased use of herbicides by farmers during the next two decades.

REFERENCES

Bertrand, A. R., SEA Integrated Pest Programs, SEA-USDA Process Publication, 69 pp., Beltsville, My, Aug. 18, 1980.

Council for Agricultural Science and Technology, Energy Use and Production in Agriculture, Report 99, 66 pp., Ames Io., Feb. 1984.

Environmental Protection Agency, Pesticide Industry Sales and Usage, 13 pp (Washington, D.C., September, 1980).

Fryer, J. D., "The Role of Research in Weed Management in the Advancing Countries," pp 104-113 in Improving Weed Management, (44, FAO, Rome, 1982).

LeBaron, H. M. "Herbicide Resistance in Plants--An Overview," Weeds Today, Vol. 14, No. 2, pp. 1-11, 1983.

LeBaron, H. and Gressel, J., "Summary of Accomplishments, Conclusions, and Future Needs," pp 349-362 in Herbicide Resistance in Plants, H. M. LeBaron and J. Gressel, eds. (New York: John Wiley and Sons, 1982).

McWhorter, C. G., Thompson, A. C., and Hauser, E. W., (Com.), Report of the Research Planning Conference on the Role of Secondary Compounds in Plant Interactions (Allelopathy), 124 pp, Mississippi State, Miss., March 15-16, 1977.

Miyamoto, J., Kearney, P. C., Takahashi, N., et al., Pesticide Chemistry: Human Welfare and the Environment, Vol. 2, 372 pp, (Oxford: Pergamon Press, 1983).

Shaw, W. C. "The ARS National Research Program," BARC Symposium No. 8, J. L. Hilton, Ed., Rowman and Allanheld, pub., (In Press), 1983.

Timmons, F. L., "A History of Weed Control in the United States and Canada," Weed Sci. 18:294-306, 1970.

Background Paper No. 20

Chemical Fertilizers

Charles H. Davis
National Fertilizer Development Center
Tennessee Valley Authority

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

PRODUCTION AND USE OF COMMERCIAL FERTILIZERS

Summary

Commercial fertilizers are materials containing one or more of the three primary plant nutrients, nitrogen, phosphorus, and potassium, in forms suitable for utilization by crops. Consumption of these fertilizers is estimated to be about 50 million tons this year with a retail value of about 8 billion dollars. About two-thirds of these fertilizers are applied as dry solids (granular) and one-third as liquids. Corn and wheat are the most heavily fertilized crops, accounting for about 43 and 11 percent, respectively, of total fertilizer consumption. Application rates of fertilizers per acre in the United States are less than for Japan and western Europe. Use of these fertilizers in these substantial tonnages is essential for maintaining U.S. agricultural productivity.

The United States is an exporter of phosphorus fertilizers (phosphates), while most (about three-fourths) of the potassium materials are imported from Canada. Net imports of nitrogen fertilizer are about 5-10 percent of consumption, but the trend to importation is expected to increase. Natural gas is the raw material for nitrogen, and phosphate ore, for phosphate products. Nitrogen and phosphate intermediates are produced in large plants located near raw material supplies and/or water transportation facilities. These intermediates, together with potassium chloride, are shipped to small plants located near the market areas. The small plants perform a number of operations, including prescription mixing of intermediates and custom application of products to the fields.

The fertilizer market is cyclical, commodity oriented, and highly competitive. The level of industry research and development (R&D) is low, estimated to cost less than 0.5 percent of sales, which is less than 10 percent of the level of overall chemical industry R&D spending. A large portion of U.S. fertilizer R&D on new products and processes is conducted by the Tennessee Valley Authority.

The high priority areas identified for fertilizer R&D are listed below. The goal for this work would be to maximize fertilizer effectiveness while minimizing costs and protecting the environment.

1. Increasing the efficiency of fertilizer use through new or improved products and methods of application with particular emphasis on nitrogen.
2. Decreasing the energy required to produce, transport, and apply fertilizers, and particularly decreasing dependence on oil and natural gas.
3. Finding more efficient means for processing U.S. phosphate rock into fertilizers with increasing emphasis on the use of the lower quality materials of the future.
4. Developing fertilizer materials and application techniques which are compatible with and beneficial to major new agricultural management systems, particularly the increasingly popular reduced-tillage practices.

New developments in the industry evolve rather slowly because of the relatively low level of R&D. Therefore, any new technology that is likely to be introduced by 1990-2000 would need to be now under development. No revolutionary or radically new products or processes appear to be near commercialization.

The future direction of energy prices will probably be the major factor affecting the rate of commercialization of new technology. Most of the current work with new processes and products was initiated when energy prices began to escalate rapidly after the OPEC embargo. Production of nitrogen is the most energy-intensive operation for the industry, particularly ammonia production. Therefore, new nitrogen technology is particularly geared to energy prices.

If real energy prices remain near present levels, the effects of new technology by 1995 are predicted to result in a 5 percent improvement in efficiency of utilization of nitrogen fertilizers from a combination of new products and better management techniques. The overall energy requirement for fertilizer production will be decreased 10-20 percent from present levels. The United States will retain the capability to produce the required fertilizers from U.S. raw materials. The cost of transportation and application of fertilizers will be decreased by about 10 percent below the cost required with the present state of technology. The phosphate industry will produce as much energy equivalent as it consumes (from cogeneration and some uranium recovery). No plants are likely to be built to produce ammonia from coal before about 2000.

If energy prices increase significantly faster than the rate of inflation, the adoption of technology related to improving efficiency of nitrogen fertilizer use and to decreasing energy for processing will be more rapid and widespread. The nitrogen industry would begin to shift to coal for raw material instead of natural gas, and the proportion of nitrogen imported would increase.

The high cost of new facilities is also a deterrent to adoption of new technology. In many situations the industry will prefer to debottleneck or add to existing plants to conserve capital.

Table of Contents

Page

Introduction 1

Current State of the Art 5

Fertilizer Use Efficiency 5

Nitrogen 5
Phosphorus 7

Decreasing Energy Required to Produce, Transport, and Apply Fertilizers 8

More Energy-Efficient Processes. 8
Avoiding Dependence on Oil or Natural Gas. 9a
Higher Nutrient Concentration in Products. 10

Research on Processing Lower Quality U.S. Phosphate Rock Into Fertilizer 11

Developing Materials and Application Techniques for Reduced Tillage Agriculture 12

New Products 12
New Application Techniques 13
Improved Means of Nitrogen Fixation. 14

Major Breakthroughs Needed and Likely Timing for Commercial Adoption 14

Economical Processes to Produce More Efficient Products 15

Reliable Technology to Make Ammonia from Coal. 15

New Ammonia, Ammonium Nitrate, and Urea Processes That are Much More Energy Efficient. 17

More Efficient Phosphoric Acid Technology. 18

Technology for Granulation of Ammonium Phosphates to Decrease Drying Requirements. 18

Higher Nutrient Concentration of Products. 19

Table of Contents (Continued)

Page

Commercialization of Technology to Use
U.S. Phosphate Containing High Levels of Carbonates. . 19

Better Fertilizer Materials and Application
Techniques for Reduced Tillage Agriculture 20
New Products Containing Sulfur 21

Institutional Arrangements. 21a

Product Evaluation 21a
Process Research 22
Application Research 22

Summary of Potential Primary Impacts. 23

References 24

Figures

1. Trend in Concentration of All Fertilizers in the United States

PRODUCTION AND USE OF COMMERCIAL FERTILIZERS

Introduction

Commercial fertilizers are materials containing one or more of the primary fertilizer nutrients nitrogen, phosphorus, or potassium in a form suitable for utilization by crops. They may also contain secondary nutrients (sulfur, calcium, and magnesium) or minor (micro) nutrients (boron, chlorine, cobalt, copper, iron, manganese, molybdenum, and zinc). Commercial fertilizers may be applied as either solids (granular) or liquids (including anhydrous ammonia). Application can be either by random spreading over the entire field area (broadcasting) or by more precise placements in relation to seeds or plants, including subsurface placement.

Current consumption of commercial fertilizers in the United States is at the rate of about 50 million tons per year with a retail value of about $8 billion per year. This includes about 11 million tons of nitrogen, 5 million tons of phosphorus (expressed as P_2O_5), and 5 million tons of potassium (expressed as K_2O). About two-thirds of fertilizers are applied as dry solids (granules) and one-third as liquids (including anhydrous ammonia).

Essentially all nitrogen fertilizer is produced from ammonia which is either directly applied or used to make urea, ammonium nitrate, ammonium phosphate, or ammonium sulfate. Natural gas is the raw material for over 95 percent of U.S. ammonia production. The United States has become a net importer of nitrogen fertilizers, and this trend is expected to continue because of relatively higher natural gas prices in the United States.

All phosphorus (phosphate) fertilizer is derived from phosphate rock which is mined as an ore and upgraded into fertilizer products, primarily ammonium phosphates or superphosphates (calcium phosphates). Approximately 75 percent of phosphate ore is derived from Florida and the remainder largely from North Carolina, Utah, and Idaho. About 90 percent of phosphate fertilizers require the use of phosphoric acid as an intermediate product; this acid is made by treating phosphate rock with sulfuric acid. The United States is a net exporter of phosphate rock and phosphate fertilizer products.

About 90 percent of potassium fertilizer is supplied as potassium chloride. Potassium chloride is derived from underground mines or from brines and separated from other salts and impurities. About three-fourths of the potassium chloride consumed in the United States is imported from Canada. The United States has extensive potash deposits, but mining and processing are more costly than for Canadian deposits.

The structure of the industry is such that intermediate products such as ammonia, urea, ammonium phosphates, and potassium chloride are produced by primary producers in large plants located near raw materials and water transportation outlets. Most phosphate production is in Florida, North Carolina, and the Gulf Coast. Nitrogen plants are mainly on the Gulf Coast or along interstate pipelines. Most potash is mainly imported from Canada, and U.S. plants are located in New Mexico, California, Texas, and Utah.

The intermediate products are combined into final products in small plants located in the market area. These plants usually combine a number of functions such as prescription product mixing, addition of pesticides, and custom application.

Production, transportation, and application of fertilizers in the United States account for less than 1 percent of national energy consumption. Production of ammonia accounts for about 70 percent of the total energy consumed in the U.S. fertilizer system (production, transportation, and application).

In 1984 approximately 43 percent of commercial fertilizers used in the United States was applied on corn, 11 percent on wheat, 6 percent on soybeans, 2 percent on cotton, and 37 percent on sorghum, rice, and other crops. The application rate of fertilizers in the United States (quantity used per acre) is substantially lower than for western Europe and Japan

Fertilizers are generally credited for accounting for 30-40 percent of agricultural production. Use of fertilizers in combination with other key inputs has resulted in threefold yield increases for corn since 1950 and substantial increases for other products.

The high priority areas identified for fertilizer research and development are listed below. The goal for this work would be to maximize fertilizer effectiveness while minimizing costs and protecting the environment.

1. Increasing the efficiency of fertilizer use through new or improved products and methods of application with particular emphasis on nitrogen.

2. Decreasing the energy required to produce, transport, and apply fertilizers; and particularly decreasing dependence on imported oil and natural gas.
3. Finding more efficient means for processing U.S. phosphate rock into fertilizers with increasing emphasis on the use of the lower quality materials of the future.
4. Developing fertilizer materials and application techniques which are compatible with and beneficial to major new agricultural management systems, such as the increasingly popular reduced-tillage practices.

The fertilizer industry only spends less than 0.5 percent of sales for research and development as contrasted to about 4 percent for the entire chemical industry. The research and development facilities that are in place by the fertilizer industry are mainly aligned with improvement of existing operating facilities. New developments evolve rather slowly. Therefore, any technology that is likely to be introduced by 1990 to 2000 would need to now be in advanced stages of development. No revolutionary or radically new products or processes appear to be near commercialization.

The future direction of energy prices will likely be the major factor affecting the rate of commercialization of new developments between now and the year 2000. Most of the current work with new technology and products was initiated as a result of the rapid increase in energy costs initiated by the OPEC oil embargo and fears that these costs would continue to escalate sharply. Stable or declining energy costs in the future will certainly slow the adoption of these developments.

A few years ago some studies created concern that the United States was about to run out of the good quality phosphate rock which is the feed material for phosphate fertilizers. This spurred interest in development of lower or "marginal" quality reserves which are abundant in Florida and some other states. It is now apparent that the good quality reserves were more extensive than some had estimated and will probably last past the year 2000. There will, however, be some decline in overall quality of phosphate before 2000 as more material of lower quality will gradually be brought into production.

Current State of the Art

Fertilizer Use Efficiency

Nitrogen. Researchers estimate that only about half of the nitrogen fertilizer applied is used by the crop during the year of application. About one-fourth of that applied is lost due to volatilization or leaching. The remainder (about one-forth of total) is fixed as organic matter in the soil and may, to some extent, be subsequently available to crops.

In recent years test products have been tagged with nitrogen isotopes to assist in delineation of pathways of loss. Loss mechanisms are primarily due to nitrification of ammonia to nitrate or nitrite by soil bacteria or to volatilization of ammonia from urea due to action of the urease enzymes in the soil.

Several new types of nitrogen products are under development that have potential to improve efficiency of use. All of these new or modified products will cost more than the conventional products now marketed. These include products with inhibitors to decrease undesirable transformations in the soil, products coated for control release, and "acidified" products that decrease ammonia volatilization after application.

Nitrogen products that contain inhibitors to decrease the undesirable microbial or enzymatic activity in the soil have been under study for years. Two products are now marketed that slow down the bacterial conversion of ammonium to nitrate (Varsa et al., 1983). They are called nitrification inhibitors. Other products of this type are under development (Gautney et al., 1983).

Coating nitrogen products to provide for a contoiled release of nitrogen is attractive as a means of improving nitrogen efficiency. If the nitrogen is released slowly as the plant can take it up, loss is less likely to occur. Several coated nitrogen products have been marketed for the high-cost specialty market. More recently, one product, sulfur-coated urea, was designed and developed for the agricultural market (TVA, Physical..., 1980). Substantial quantities (several thousand tons per year) are now being produced, but most is presently sold for turf and horticultural uses because this market brings a premium price in comparison to agricultural markets.

Urea can be "acidified" to decrease the tendency to volatilize ammonia. This results from a low pH at the microsite surrounding the fertilizer granule (TVA, Use..., 1983). Reaction of urea with mineral acids such as phosphoric and sulfuric acids can give this effect. Experimental products based on a urea-phosphoric acid adduct called urea phosphate are under study. Products containing urea with sulfuric acid are being marketed on a limited basis.

Closer and more precise placement of nitrogen in relation to seed may also enhance efficiency of use. However, salt effect and/or ammonia volatilization can damage seed. Both urea phosphate and sulfur-coated urea are attractive as products that may be suitable for close placement without inhibiting germination.

Phosphorus. Some researchers report that probably only about 20 percent of the applied phosphorus fertilizer is used in the year of application. However, unlike some of the nitrogen, the unused phosphorus is not lost; it is fixed in the soil in insoluble forms and may be available for subsequent crops.

Use of "acidifying" products such as urea phosphate may enhance recovery of phosphorus by resolubilizing some of that which has been "fixed" by chemical reactions in the soil. Also, as with nitrogen, precision placement of phosphorus fertilizer is a promising means of increasing recovery. Considerable research is underway of the effects of placement on crop yield.

Decreasing Energy Required to Produce, Transport, and Apply Fertilizers

More Energy-Efficient Processes. Production of ammonia has a theoretical energy requirement of about 20 million Btu's per ton of product. Prior to the oil embargo most U.S. ammonia plants required the energy equivalent of nearly 40 million Btu's per ton. The escalation in energy prices resulted in design of new plants that are more energy efficient and also retrofitting of old plants to improve efficiency. Improving efficiency resulted in increased capital costs. Recently Pullman-Kellogg Division of Pullman, Incorporated reported construction of what they believe to be the most energy-efficient design proved in actual operation. This plant was said to require only 25 million Btu's per ton ammonia (Anon., 1983).

Several new urea processes have been announced that would decrease energy requirements by 25-50 percent as compared with the reported U.S. plant average (Dooyeweerd et al., 1983). Some of these plants are now either under construction or in operation.

New, more energy-efficient technology for production of nitric acid and ammonium nitrate has been developed in Europe (Blouin, 1983). This technology includes energy recovery in the nitric acid plant and steam recovery from the neutralization step. Overall energy requirement is much less than for most U.S. plants which were constructed before the OPEC embargo.

New phosphoric acid technology is under development that more efficiently uses the heat of reaction to avoid requirements for steam in concentrating the product by evaporation. These systems are called "hemihydrate" processes because that is the crystalline form of the by-product calcium sulfate. Such technology can save about 3 million Btu's per ton P_2O_5 as compared with typical U.S. plants (Davis et al., 1977). Some relatively small plants are in operation with the hemihydrate process in Europe, one large plant is operating in the United States, and another U.S. plant is being modified to incorporate the hemihydrate process.

Phosphoric acid for fertilizers is produced by treating upgraded (beneficiated) phosphate rock with sulfuric acid. The sulfuric acid is produced in adjacent plants by burning sulfur. This oxidation of sulfur generates heat which can be utilized to produce steam for production of electricity or other uses. Several U.S. plants are producing electrical power from cogeneration at sulfuric acid plants (Leon et al., 1980).

Most phosphoric acid used for fertilizers is processed into granular ammonium phosphates. These products were normally made by granulation of a water slurry followed by drying. Recently processes have been developed that more efficiently utilize the heat of ammoniation of the phosphoric acid to evaporate water, thereby avoiding or decreasing drying requirements (Achorn et al., 1983).

Florida phosphate rock contains about 1 pound of uranium oxide (yellow cake) per ton of P_2O_5. This yellow cake is retained in the phosphoric acid produced from the phosphate rock by sulfuric acid treatment. Technology is available for recovery of the yellow cake by solvent extraction and is being utilized in one operating plant. Economics of recovery are not attractive at present energy prices, but more plants will commence recovery operations as energy prices increase.

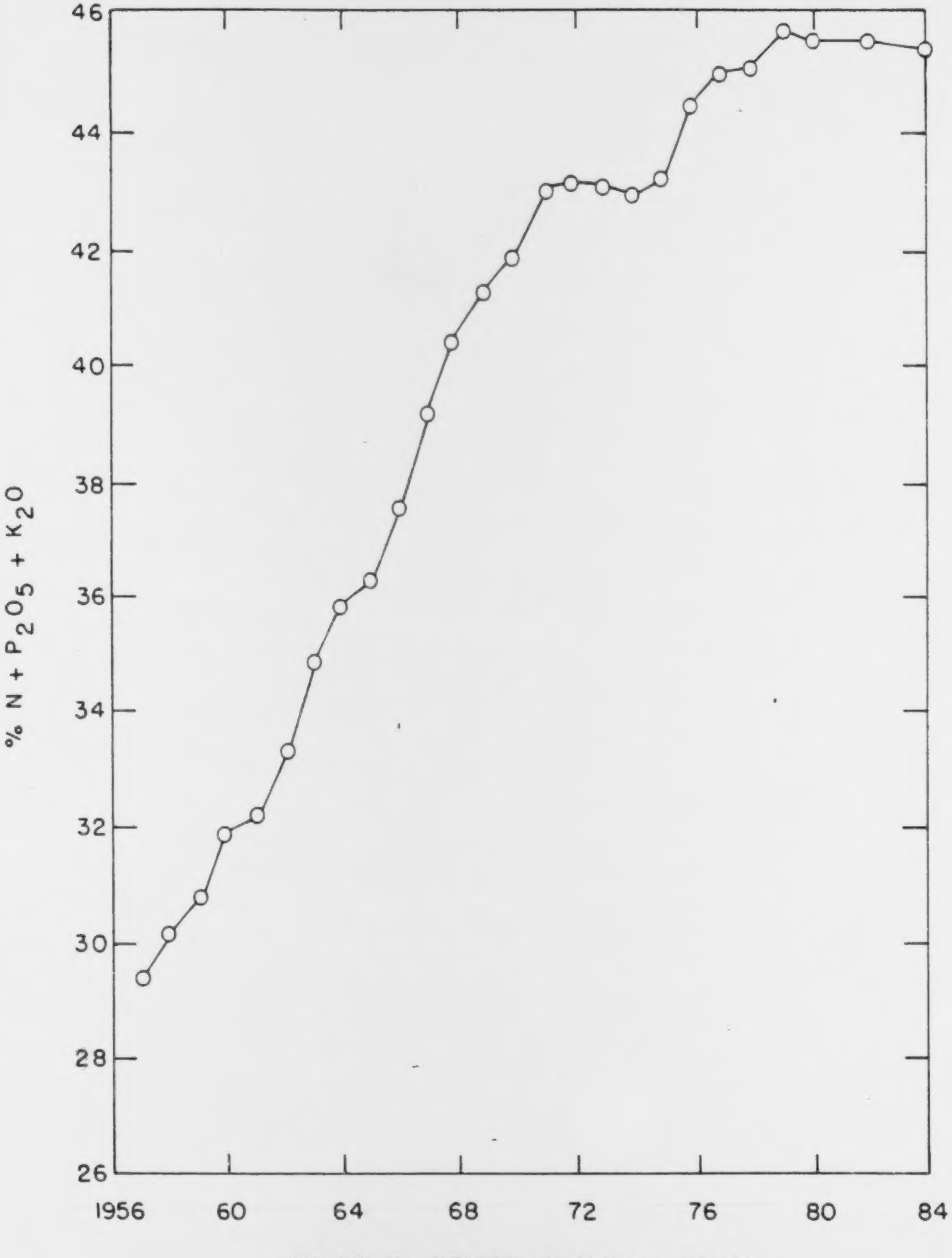
The energy value of the yellow cake is at least 10 times the energy required to produce the phosphoric acid.

Avoiding Dependence on Oil or Natural Gas. Since over 95 percent of U.S. ammonia production is based on natural gas for feedstock and energy, the nitrogen fertilizer industry is now highly dependent on natural gas. U.S. reserves of natural gas are only equivalent to about 10 years of needs based on present use rates. In contrast, U.S. resources of coal are much higher, probably equivalent to more than 10 times the equivalent of gas reserves on an energy basis.

Technology for production of ammonia from coal is in advanced stages of development. The Texaco process, which produces a synthesis gas at pressures and compositions that are suitable for ammonia production, has been demonstrated satisfactorily in a 200 tons of coal per day unit with various types of U.S. coal (Waitzman et al., 1983).

Granular mixed fertilizers are normally produced by processes that require a drying step after granulation. Fuel oil or natural gas is used to supply heat for drying. Fuel energy requirements are normally about 500,000 Btu/ton product. Technology in advanced stages of development and early stages of commercialization would completely eliminate any need for drying of some types of products.

Higher Nutrient Concentration in Products. About 13 percent of the total energy required for the U.S. fertilizer supply system is associated with transport, handling, and application of fertilizers (Davis et al., 1977). Increasing the nutrient concentration of fertilizers so that fewer tons could supply the same quantity of product is an obvious means for decreasing the energy expended for transport and handling. As shown in Fig. 1, the nutrient concentration of U.S. fertilizer



TREND IN CONCENTRATION OF ALL FERTILIZERS IN THE UNITED STATES

Figure 1

products has been steadily increasing. Recent trends to use of ammonium phosphates instead of superphosphates (primarily calcium phosphates) and to use of urea (46 percent N) instead of ammonium nitrate (34 percent N) are contributing to the increase in nutrient content. The trend to use of liquid suspensions instead of clear liquids is also a factor in increasing nutrient concentration because some suspension mixtures contain up to about twice the nutrient concentration of clear liquids.

Research on Processing Lower Quality U.S. Phosphate Rock Into Fertilizer

About three-fourths of U.S. phosphate rock production is in central Florida, mainly in the Polk County area. This phosphate is mined by open pit methods and upgraded (beneficiated) to give a concentrate that is suitable for production of phosphoric acid or superphosphates. The major impurities are clays and silica (sand) which are removed by washing followed by flotation-type separation operations.

The best quality phosphate material is gradually being depleted in the Polk County region and mining operations are beginning in counties just south of the present area, called the "Southern Extension." Phosphate material in the Southern Extension is reported to be of lower grade, require deeper mining, and generally contain larger quantities of calcite and dolomite impurities (calcium and magnesium carbonates) (Lawver et al., Phosphate..., 1982). Calcite and dolomite cause foaming and consume sulfuric acid during wet-process phosphoric acid manufacture and can also contribute impurities to the product acid and products made from it.

Research is in progress on means for removal of these carbonates. The International Minerals and Chemical Corporation (Lawver et al., Beneficiation..., 1982), U.S. Bureau of Mines (USDI 1982), and TVA (Lehr et al., 1981) have all piloted flotation processes for dolomite removal by flotation. Substantial test work is also in progress to determine the effects of increased impurity levels on product quality and effectiveness. Results so far show that some increases in levels of impurities can be tolerated without adversely affecting product quality (Nielsson et al., 1979).

Developing Materials and Application Techniques for Reduced Tillage Agriculture

Reduced tillage agriculture is steadily increasing in importance. Acreage under reduced tillage has increased from 44 million in 1973 (Christensen et al., 1983) to 87 million at present (Conservation, 1984).

New Products. Use of urea in reduced tillage agriculture poses special problems because of the potential for hydrolysis and subsequent volatilization of ammonia from the soil surface. Sulfur-coated urea, urea with urease inhibitors, and acidified urea (urea phosphate or urea sulfate) are new products under study that have potential for decreasing ammonia loss from surface-applied urea. The ultimate degree of utilization of these products will probably be determined by their cost premium in relation to straight urea.

Other research in earlier stages has indicated that incorporation of certain divalent cations such as Ca^{++} or Mg^{++} can decrease ammonia volatilization in surface application (Anon., 1981). This raises the prospect for incorporation of calcium nitrate into urea or into acidified urea. Such products might be produced by a processing system involving acidulation of phosphate rock with nitric acid to produce calcium nitrate and phosphoric acid followed by addition of urea to fix the phosphoric acid as urea phosphate. Such a system is attractive because it could result in production of a more efficient nitrogen fertilizer containing low-cost phosphate (supplied directly by phosphate rock).

Sulfur-coated urea and urea phosphate also are being studied for their suitability in application with seed in reduced tillage systems. Both products have low salt effects and low tendency to evolve ammonia which can damage seed.

New Application Techniques. Growth of reduced tillage has necessitated development of special application techniques to fit this management practice. This system has resulted in emphasis on precision placement and on simultaneous application of seed and fertilizer and also conduct of other operations in the same pass across the field. This has prompted development of new types of equipment.

The major areas of application research involve (1) deep placement of fertilizer underneath seed; (2) strip or band application near seed, including dribble application of liquids; and (3) placement of fertilizer with seed.

Improved Means of Nitrogen Fixation. Recently biological nitrogen fixation and improved, low-energy means of chemical nitrogen fixation have been publicized. These areas of research have attractive future potential and should be encouraged. However, the state of this technology is such that commercialization prior to the year 2000 is highly unlikely.

Major Breakthroughs Needed and Likely Timing for Commercial Adoption

It is unlikely that any major new breakthrough will occur that will be commercialized between now and the year 2000. Rather, some of the technology already in research and development will be adopted and some that is already in early stages of adoption will be adopted more extensively.

The major determining factor in the rate of adoption of new technology will be energy costs. Therefore, two scenarios will be considered for future energy prices—(1) prices advance at the rate of inflation or less or (2) prices in 1995 are 100 percent higher than current prices after adjustment for inflation (e.g., if oil prices are $27 per barrel in 1984 they would be $54 /1984 dollars/ per barrel in 1995). The lower price scenario (prices advance at inflation rate or less) seems much more likely at this time.

Even when use of new technology is attractive, the high capital cost of new facilities will be a major deterrent. Historically, the the fertilizer industry has been very successful in increasing capacity in a cost effective way by debottlenecking or expanding existing facilities.

Economical Processes to Produce More Efficient Products. The new products most likely to attain commercialization are (1) urea phosphate and urea-urea phosphate combinations, (2) additional products with nitrification inhibitors, products with urease inhibitors, sulfur-coated urea, and urea phosphate-calcium nitrate combinations produced by systems involving acidulation of phosphate rock with nitric acid.

With the low-cost energy scenario, a substantial degree of commercialization is unlikely. Breakthroughs that could enhance commercialization include (1) finding lower cost routes for synthesis of one or more of the effective nitrogen-loss inhibitors, and (2) developing an economical process to granulate urea phosphate-type products, including those produced by acidulation of phosphate rock with nitric acid followed by addition of urea to the acidulate.

Under the high-energy cost scenario, significant commercialization of all the products mentioned above would be likely. This is primarily because the high cost of nitrogen fertilizers would greatly enhance the economic incentives for improving recovery efficiency.

Reliable Technology to Make Ammonia From Coal. The capital cost of a coal-based ammonia plant will be about twice the cost for gas-based plants, and maintenance and operating costs will also be higher (TVA, Ammonia..., 1983). Therefore, developing reliable, modern technology that will permit high on-stream time (90 percent or more) for coal-based plants will be a major factor affecting their economic competitiveness with gas-fed plants. Development of such reliable technology is in progress for coal-based operations and should be well advanced by 1990. Therefore, the major factors affecting commercialization of coal-based plants are (1) the relative costs of coal and natural gas and (2) the cost of imported ammonia.

Coal-based ammonia production will probably become competitive with gas-based operations when the cost of gas exceeds the cost of coal by a factor of 4 on an energy basis. At the present time the cost of gas energy to ammonia producers is less than twice the cost of coal energy. (Gas costs average about $3 per 1000 cubic feet as compared with coal at about $30 per ton.) Gas prices are expected to increase more rapidly than coal, but the rate of increase would be much more rapid under the high-energy scenario. Under the low-energy scenario, no production is expected before the year 2000.

Ammonia can be produced in some other countries, such as those in the Middle East, Mexico, and Canada from low-cost natural gas at costs much lower than those from either gas or coal-based U.S. plants. In some situations the gas price is set or regulated by the Government. This ammonia may be priced at whatever level is required for sale into U.S. markets. If U.S. policy allows this to occur, it is unlikely that new ammonia capacity will be built in the United States.

New Ammonia, Ammonium Nitrate and Urea Processes That are Much More Energy Efficient. Adoption of this technology is already in progress in both new plants and in modifications to existing plants. The degree of adoption will be dependent on future energy costs. This is because the more energy-efficient processes have higher capital costs (due to more extensive energy recovery equipment). For example, new ammonia plants that require about 30 million Btu's to produce a ton of ammonia are becoming the norm as compared with plants that required about 38 million Btu's 5 years ago. Under the high-energy-cost scenario, plants that require as little as 25-26 million Btu's would probably become the norm. Similarly, urea processes requiring 50 percent less energy than those of 10 years ago are being commercialized. Further penetration of these plants with additional efficiency improvements would be expected under the high-energy-cost scenario.

More Efficient Phosphoric Acid Technology. Phosphoric acid technology is under development that could conserve at least 3 million Btu's per ton P_2O_5 as compared with present technology. No technical barriers are apparent, but capital and operating costs may be higher for the new technology; therefore, the degree of commercialization will primarily be dependent on future energy costs. With the low-energy-cost scenario, adoption of this new technology in the 1990-2000 timeframe is unlikely. With the high-energy-cost scenario, construction of new plants with this design by 1995 will probably occur.

In related developments, at least three U.S. phosphoric acid producers are recovering electrical power from the plants that burn sulfur and produce the sulfuric acid. The sulfur combustion generates a large quantity of heat that is amenable to practical means of power recovery. Under either scenario of future energy costs, it is likely that new plants constructed in the 1990s will incorporate these power generation features.

Technology for Granulation of Ammonium Phosphates to Decrease Drying Requirements. Adoption of this new technology for production of granular monoammonium phosphate (MAP) is already in early stages of commercialization. Similar technology is also in advanced stages of development and undergoing plant-scale testing for granular diammonium phosphate (DAP). This technology is suitable for retrofitting into existing plants or for incorporating into new plant designs.

If energy costs remain constant, probably essentially all MAP and some DAP will be produced by the new technology after 1995. Under the high-energy-cost scenario, probably almost all granular ammonium phosphates (over 15 million tons per year of granular DAP and MAP) would be made with the low-energy processes.

Higher Nutrient Concentration of Products. The concentration of fertilizers in the United States has been steadily increasing--from about 30 percent nutrient in 1960 to about 46 percent in 1983. This is mainly because of the trend to urea (46 percent nitrogen) to replace ammonium nitrate (34 percent nitrogen) and ammonium phosphate (about 64 percent nutrient) to replace superphosphate (about 20-45 percent nutrient). The use of suspension mixtures instead of liquids also substantially increases (sometimes doubles) the nutrient concentration of fluid products.

With the lower-energy-cost scenario, the trend to higher nutrient concentration is expected to continue, since transportation, handling, and application can account for 25 percent of the applied cost of fertilizer. If energy costs escalate in accordance with the higher-cost scenario, the rate of increase in concentration will probably be slightly higher.

Commercialization of Technology to Use U.S. Phosphate Containing High Levels of Carbonates. The commercialization of this technology will be largely independent of energy costs and is destined to become a reality at some point in time because of extensive U.S. resources of this type and limited reserves of higher purity material. Fertilizers are highly competitive commodities, and removal of carbonates will require an additional processing step at significant costs. Therefore, U.S. phosphate producers have been diligently seeking higher grade phosphate reserves in Florida that can be processed without a carbonate removal step. This has involved extended prospecting efforts and also buying unexploited reserves from others. Because the industry has been successful in securing reserves that won't require a carbonate removal step, it now seems unlikely that any significant commercialization of processes utilizing high-carbonate ores will occur in Florida before about 2000. However, in the decade thereafter commercialization of these ores will probably become a reality.

Better Fertilizer Materials and Application Techniques for Reduced Tillage Agriculture. Development of this technology is proceeding and progress of adoption will be influenced in part by energy costs and also by the need to decrease soil erosion and conserve water. Significant commercialization is anticipated by 2000. It is unlikely that any "quantum" development will occur that will revolutionize this area of technology. Progress will probably consist of a series of improvements from progressive developments. Urea phosphates, MAP, urea with urease inhibitors, and sulfur-coated urea are products that will probably gain adoption, to some extent, with this type agriculture. Urea phosphate, sulfur-coated urea, and urea with urease inhibitors have advantages for surface application, and the former two products along with MAP may be preferable for close placement with seed.

New Products Containing Sulfur. Although it is classified as a secondary plant nutrient, sulfur requirements for agricultural productivity approximate those needs for phosphorus and potassium. There are regions in the United States where soils are deficient in sulfur, and consequently sulfur fertilization is necessary for satisfactory agricultural productivity. In other regions the sulfur fertility levels of the soil are such that there is no crop response to sulfur fertilization. The major sulfur-deficient areas are in parts of the south central, southeastern, northwestern, north central, and Great Plains States.

Areas of sulfur deficiency can be expected to become more acute. This is due to (1) decline in use of the major sulfur-bearing fertilizers such as normal superphosphate and ammonium sulfate and (2) less sulfur emitted from stack gases that result utimately in sulfur deposition suitable for plant uptake.

A number of new sulfur-bearing products are either in advanced stages of development or early stages of commercialization. These include both liquid and granular materials. For most of these products the sulfur is present as either ammonium sulfate (produced in situ from the reaction of ammonia and sulfuric acid) or as finely divided elemental sulfur. New granular nitrogen materials based on urea with sulfur (as either elemental sulfur or ammonium sulfate) are becoming popular in the northwest. Some western ammonium phosphate producers are granulating gypsum into ammonium phosphate products as a sulfur nutrient source.

Institutional Arrangements

The major part of research and development of new fertilizer products and processes in the United States is conducted by the Tennessee Valley Authority (TVA) at the National Fertilizer Development Center (NFDC) located at Muscle Shoals, Alabama. Fertilizer industry companies devote a relatively small proportion of their assets to research and development in comparison to other chemical industry, and the level of input varies in accordance with fertilizer business cycles. The land-grant universities and the United States Department of Agriculture (USDA) have substantial involvement in product evaluation and in development of farm management techniques, including fertilizer application. The Florida Institute of Phosphate Research, which is funded by a state tax on products, contracts for phosphate research in areas primarily involving environmental protection and by-product utilization. The U.S. Bureau of Mines researches areas relative to mining operations and mineral reserves. Engineering firms are involved in development of improved processes, and trade associations, in evaluation of products and development of application equipment. Communication and cooperation among the various institutions involved in fertilizer research and development are generally good with TVA and fertilizer trade associations (The Fertilizer Institute, the National Fertilizer Solutions Association, and the Potash and Phosphate Institute) as the focal points.

Product Evaluation. TVA is heavily involved in the physical and agronomic evaluation of new products. TVA contracts with land-grant universities and cooperates with industry companies for testing of new products. Other product research is carried out by the USDA which is headquartered at Beltsville, Maryland; the National Fertilizer Solutions Association, Peoria, Illinois, and the Phosphate-Potash Institute, Atlanta, Georgia. Additionally, some industry companies are directly involved in product evaluation.

Process Research. Most basic fertilizer process research and development is conducted by TVA. The larger industry firms (primary producers) also are involved in research and development, primarily in improvements or modifications to processes they operate. The engineering firms experienced in constructing fertilizer plants also conduct process-related developments; this has been particularly pronounced in the areas of production of phosphoric acid, ammonia, ammonium phosphates, and urea.

Application Research. Application research and development is conducted by TVA, application equipment manufacturers, trade associations, and universities. TVA's role here is primarily in evaluation of suitability of certain types of equipment with specific types of products. The universities and fertilizer industry trade associations are involved in evaluation of certain types of products and equipment in particular farm management situations. Equipment research is conducted by equipment manufacturers.

Summary of Potential Primary Impacts

Potential primary impacts likely from the new technology under development by about 1995 are listed below based on either the low-cost-energy scenario or the high-cost scenario. Probably the most significant developments are in the area of improving fertilizer efficiency, where a 10 percent improvement would save farmers $0.5-1 billion per year based on current prices.

Low-energy-cost scenario (Energy cost increases at or less than inflation rate)	High-energy-cost scenario (Energy cost increases significantly higher than inflation rate)
5% improvement in efficiency of utilization of fertilizers	10% improvement in efficiency of utilization of fertilizers
Energy required to produce fertilizers decreased by 10-20% from present levels	Energy required to produce fertilizers decreased by 20-30% from present levels
United States has capability to produce required fertilizers from domestic raw materials	Same
[1]Cost of transportation and application of fertilizers decreased by 10%	Same
[2]Phosphate fertilizer industry develops energy self-sufficiency	[2]Phosphate fertilizer industry becomes net producer of energy
Two or three coal-based ammonia plants would be in advanced stages of planning	New ammonia plant capacity would be based on coal feed.
Several types of new products containing nutrient sulfur are commercialized	Same

---

[1] As compared to cost if no new developments were achieved.

[2] Includes some energy credit for recovery of uranium.

References

Achorn, F. P., and Salladay, D. G., "Latest Developments in Use of the TVA Rotary Ammoniator-Granulator," paper presented at the Diamond Jubilee Meeting of the American Institute of Chemical Engineers, Washington, D.C., Oct. 30Nov. 4, 1983.

Anon., "Modified Urea Decreases Nitrogen Losses," Agrichemical Age 25(8), 39, 46, Aug./Sept. 1981.

Anon., "Sherritt," Nitrogen (43), 16-20, May/June 1983.

Blouin, G. M., "Comparison of Energy Requirements for Production of High-Nitrogen Mixed Fertilizer by the Nitrophosphate Route with the Urea-Ammonium Phosphate Route," paper presented at the Diamond Jubilee Meeting of the American Institute of Chemical Engineers, Washington, D.C., Oct. 30Nov. 4, 1983.

Christensen, L. A., and Magley, R. S., "Conservation Tillage Use," Journal of Soil and Water Conservation 38(3), 156-157, May-June 1983.

Conservation Tillage Information Center, "1983 National Survey Conservation Tillage Practices, Executive Summary," National Association of Conservation Districts, Washington, D.C., 1984.

Davis, C. H., and Blouin, G. M., "How Much Energy Does Fertilizer Consume?" *Farm Chemicals* *140*(6), 18-20, 22, June 1977.

Dooyeweerd, H., and Meessen, J., "Comparison of the Energy Consumptions of Low-Energy Urea Technologies," *Nitrogen* (143), 32-38, May-June 1983.

Gautney, J., Kim, Y. K., and Gagen, P. M., "Feasibility of Cogranulating the Nitrogen Loss Inhibitors Dicyandiamide, Thiourea, Phenyl Phosphorodiamidate, and Potassium Ethyl Xanthate with Urea," paper presented at ACS 168th National Meeting, Washington, D.C., Aug.-Sept. 1983.

Lawver, J. E., et al., "Beneficiation of Dolomitic Phosphate Reserves," XIV International Mineral Processing Congress, Toronto, Ontario, Oct. 1982.

Lawver, J. E., Snow, R. E., Wiegel, R. L., et al., "Phosphate Reserves Enhancement by Beneficiation," *Mining Congress Journal* *68*(12), 27-31, Dec. 1982.

Lehr, J. R., and Hsieh, S. S. (Tennessee Valley Authority), "Beneficiation of High Carbonate Phosphate Ores," U.S. Patent No. 4,287,053, Sept. 1981.

Leon, V. E., Kelley, J. C., and Porch, H. P., "Design Options for Energy Conservation in a Fertilizer Complex," Proceedings of 30th Annual Meeting Fertilizer Industry Round Table 1980," 60-82, Atlanta, Ga., Oct. 1980.

Nielsson, F. T., and Baumann, A. N., "Some Operating Experience Using High-Magnesium Phosphate Rock in Wet-Process Phosphoric Acid Manufacture," Fertilizer Acids: Proceedings of British Sulphur Corporation's Third International Conference on Fertilizers, Part I, Paper 16, Nov. 1979.

Tennessee Valley Authority, "Ammonia from Coal," New Developments in Fertilizer Technology—14th Demonstration, TVA Bulletin Y-181, 105-107, Muscle Shoals, Ala., Oct. 1983.

Tennessee Valley Authority, "Physical Properties of TVA Sulfur-Coated Urea," New Developments in Fertilizer Technology--13th Demonstration, TVA Bulletin Y-158, 17-20, Muscle Shoals, Ala., Oct. 1980.

Tennessee Valley Authority, "Use of Urea-Urea Phosphate and Sulfur-Coated Urea for One-Pass Wheat Seeding and Fertilizer Application With Limited-Tillage Wheat," New Developments in Fertilizer Technology—14th Demonstration, TVA Bulletin Y181, 34-39, Muscle Shoals, Ala., Oct. 1983.

U.S. Department of the Interior, Bureau of Mines, "Application of Carbonate-Silica Flotation Techniques to Western Phosphate Materials," U.S. Bureau of Mines Report No. RI8728, 1982.

Varsa, E. C., and Huber, D. M., "Nitrogen Inhibitors Worth A Look," Solutions 27(2), 60, Feb. 1983.

Waitzman, D. A., Lee, R. G., Nichols, D. E., et al., "Progress Report on Ammonia Production from Coal by Utilization of Texaco Gasification Process," paper presented at the Diamond Jubilee Meeting of the American Institute of Chemical Engineers, Washington, D. C., Oct. 30-Nov. 4, 1983.

Background Paper No. 21

Organic Farming

William Liebhardt
Rodale Research Center
and
Richard Harwood
Winrock International

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

TABLE OF CONTENTS

Summary ii

Introduction 1

Sources of Information 2

Definition and Scope of Organic Agriculture 3

An Assessment of Farm-Level Comparisons 4

Nitrogen Self-Sufficiency in Cropping Systems 7

Nutrient Cycling Efficiencies 13

Soil Erosion 22

Problems of Conversion 23

Insect Pest Management 24

Insect-Repellant Plants 28

Allelopathy 29

Disease-Suppressive Soils 30

Summary of Organic Agriculture - Related Technologies with Potential for Further Use 31

Institutional Changes Needed: The Need for a Broadened Research Paradigm 32

Likely Timing of Commercial Introduction 35

Potential Impacts 36

References 38

Summary

Organic agriculture has been reviewed for its potential for contribution to the U.S. agriculture of the future. Scientific data useful for this evaluation have been accumulated only for the last six to eight years as the scientific method has been applied, on a very limited scale, to evaluation and understanding of modern organic systems. The data are thus preliminary, but indicate significant potential for contribution in several areas. Those subject matter "clusters" are:

1. The integration of a multitude of practices in organic systems results in lower input costs and lower energy inputs in farm practice. Purposeful structuring of the system is required.

2. Nitrogen self-reliance is possible in fieldcrop systems.

3. Nutrient cycling efficiencies seem pronounced under organic field crop management.

4. Soil test and nutrient need assessment practices require modification.

5. Soil erosion can be controlled through organic management.

6. Problems of conversion from conventional to organic or lower input systems seem nutrient-related.

7. Several new insect management strategies and technologies are indicated from organic practice and research.

8. Allelopathy could be a useful weed management tool.

9. Disease-suppressive soil management may be possible.

It seems apparent that a broadened research paradigm is crucial to the realization of several of these potentials. The overall integration of several complex subsystems into a resource and energy-efficient whole requires considerable change in thinking about the relationship of technology, farm management goals and the agroecology of farming systems.

The potential for impact on U.S. agriculture during the next ten years is enormous.

Introduction

Our goal in this paper is to review organic agriculture for its potential contributions to the U.S. agriculture of the future.

In so doing we do not wish to deal in philosophy, but in biological fact. It must be kept in mind, however, that there are two quite different approaches (some call them paradigms) involved. That of conventional agriculture is to reduce the effective boundaries of a production systems to a single crop in a single field in one season. Any production inputs needed to stabilize this system both biologically and economically are used. Because, for the most part, the biology of the system is structured, by way of inputs, to conform to the needs of the single crop in order to arrive at an optimum yield. This approach has been labeled the "dominance" approach to agriculture. Research on such systems is discipline-oriented and deals with individual components. In organic agriculture the effective "system" boundary is extended to (usually) include an entire farm or management unit, its crop or animal enterprise mix, the crop rotation or sequence and the flow of materials through the systems over time. The terms "reductionist" versus "wholistic" have been used to describe differences in approach, but they have come to imply value judgement and thus must be used with caution. We approach the challenge of this review as scientists trained in and having spent most of our professional careers working with conventional agriculture. Work with organic agriculture has meant to us the application of scientific principle to the study of larger systems. It has brought us to view agriculture as the purposeful manipulation of biological processes to achieve stability at high levels of productivity a decidedly different viewpoint from that of "control" in which we were trained. We speak from that "organic" perspective (some may call it "bias").

Sources of Information

The concepts of the diverse "schools" of thinking in alternative agriculture were reviewed by Boeringer, et al (1980). This review, originally completed in 1976, marked the beginning of the present-day "scientific era" of alternative agriculture. The historical writings of the various schools were reviewed by Harwood (1983). Little direct scientific evidence for the advantages claimed for organic systems can be found in the pre-1976 "classic" literature of the various movements. Much of the work is in the form of testimonial or of observations reported by (often keen) observers. There are a multitude of scientific questions or hypotheses to be derived from these writings, but little factual proof is given. Since 1976 several research programs in both Europe and the U.S. have begun to generate data. Several farm-focused studies have been done, and an increasing number of controlled, replicated experiments are underway. We will draw from all of these.

Definition and Scope of Organic Agriculture

The USDA (Papendick, et al, 1980) defined organic farming as "a production system which avoids or largely excludes the use of synthetically-compounded fertilizers, pesticides, growth regulators, and livestock feed additives. To the maximum extent feasible, organic farming systems rely upon crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivations, mineral-bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients and to control insects, weeds, and other pests."

Organic farms also might be divided into types according to enterprise makeup and method of structuring biological interactions (Harwood, 1984). The major types of organic farms are mixed-field crop systems, integrated crop-livestock systems, vegetable farms and fruit crop systems (tree and vine crops). Mixed field crop farms with or without animals have the greatest short-term potential for conversion to organic farming practices because crop combinations and rotations give the greatest economic advantage with these crops.

It must be remembered that organic agriculture, in practice, employs many of the same processes of conventional agriculture, but may integrate them to a far greater extent. We, therefore, include them in this discussion because of the potential to use them far more widely.

We will limit our discussion to those characteristics of organic agriculture that have been cited as having relevance to problems now being widely perceived in conventional systems.

An Assessment of Farm-Level Comparisons

In recent years a series of studies of whole farms have been done as farm comparisons or as single farm case studies (Roberts, et al, 1979; Lockeretz, et al, 1981; Cunningham, E.A. 1982. Organic farming in eastern Nebraska. M.S. thesis (unpublished). Un. of Nebraska, Lincoln, NE.; Patten, 1982. Comparison of nitrogen and phosphorus flow on an organic and conventional farm. M.S. thesis (unpublished), Dept. of Ag. and Soils. Washington State Univ; Bolton H. Jr., 1983. Soil microbial biomass and selected soil enzyme activities on an alternatively and a conventionally managed farm. M.S. thesis (unpublished) Washington State Un., Pullman, WA. ; Culik, et al, 1983; Wegryzn, 1984. Nitrogen fertility management in corn -- a case study on a mixed crop-livestock farm in Pennsylvania. Ph.D. thesis (unpublished). PA State Univ.; and Kaffka, personal communication, 1984). It must be recognized that these data can be viewed as indicative but not definitive. For example, soil erosion is generally reduced in organic systems in comparison with conventional farms. This is a result of more sod crops in the rotation; however, it should be remembered that sod crops also reduce erosion in a conventional system. All of the studies have the weakness of non-random sampling of farms, of varying degrees of precision and completeness in data gathering and of limited numbers of farms in the studies. The most extensive data are those of Lockeretz (1981), while the most exact and complete single-farm data are those of Culik (1983). While such data may have weaknesses, it must be remembered that in selecting organic farms for study one must sample from a "universe" of farms which comprises a very small percentage of total farms. Organic farms differ in structure, size, farm management capabilities, proximity to market and in physical environment. The studies, for the most part, have dealt with these problems admirably well.

Lockeretz, et. al. (1980 and 1981) compared the corn yields of 26 paired comparable organic and conventional mixed grain livestock farms in the late 1970s in the western corn belt over a wide range of soil types. The mean yield of corn (Zea mays L.) from the conventional fields was 8.5% higher than the matched organic fields but this difference was not statistically significant. Conventional corn yields tended to be higher than organic corn yields under favorable growing conditions; however, conventional corn yields were lower when conditions were adverse (drought). Grain from conventional fields had a significantly higher crude protein content, stalk rot (Diplodia), and lodging. Soils from organic fields had a significantly higher organic C content, higher total N, but lower Bray 1 phosphorus. Differences in Bray 2 phosphorus, exchangeable K, C:N ratio, CEC, and pH were not significant. The organic farms required about two-fifths as much fossil energy to produce one dollar's worth of crop.

Pimentel, Berardi and Fast (1983) compared conventional with organic corn and wheat (Triticum aesitivum L.) production and found that organic corn and wheat were 29-70% and 35-47% more efficient than conventional systems with respect to energy use.

The long-term sustainability of organic or low-input farms is very apparent in research on complete farms. Culik, et al (1983) reported results of a five-year study (1978-1982) on a 320-acre crop/livestock farm in eastern Pennsylvania which had been farmed using low-input, biological resources, since 1973. Yields of the crops were 10% above state and county averages, soil fertility levels were maintained or increased, erosion was reduced, and production costs were 10% less than conventional, high-input farms. Inclusion of forage legumes can be a problem for cash grain farmers because it could reduce their income or result in the production of a crop which is harder to dispose of.

The summary by Geisler (1980) pretty much states the conclusions that have been drawn from all of these studies. These conclusions are:

1. Yields per acre are generally equivalent or slightly less than those of conventional agriculture. Some farms have significantly higher than average yields.
2. Few or no insecticides, fungicides or herbicides are used.
3. Production costs are lower by up to 30%, averaging about 12% lower.

4. Energy inputs per unit produce are 50 to 63% less.

5. A higher proportion of production cost is comprised of labor and machinery cost than on conventional farms.

6. Soil erosion is significantly reduced.

It must be remembered that these studies are exclusively from integrated crop-livestock or field crop farms. None are from vegetable or fruit operations. Secondly, the data are suggestive because of limitations of the case study approach. It must be argued, however, that taken as a whole the studies lend sufficient credibility to the six conclusions listed above to warrent continued research both on a whole farm basis with wide sampling of farms and on a controlled, field plot level. The striking results, if true, could have real significance to a large proportion of U.S. farms growing similar crops. The environmental implications of reduced disruption from agriculture are highly significant.

Nitrogen Self-Sufficiency in Cropping Systems

One of the most significant factors in reducing production costs and energy inputs in the organic field crop systems studied was the nitrogen self-reliance of all of the study farms. Few, if any of the farms imported nitrogen at all onto the farm and those that did brought in relatively small amounts. Likewise none of the farms sacrificed cash crops for nitrogen-fixing cover crops. This was achieved by integrating legumes into the farming system. The inclusion of such crops is in no sense unique to organic agriculture but it is decidedly more pronounced on these farms. That it is important to the future of U.S. agriculture is borne out by Burgess (1983).

She states that at present 50 million tons per year of industrial nitrogen fixation occurs for agriculture. Biological nitrogen fixation on a global scale accounts for 90 million tons per year in agricultural soils. The cost of a fertilizer plant using Haber-Bosch technology has increased from $15 million in the mid-1960s to a projected $300 million in 1990, a 20 fold increase. No new plants have opened in the U.S. in recent years, and 25 have closed since 1977. "The demand for agricultural nitrogen over the course of the next 30 years cannot be met by Haber-Bosch technology alone. New strategies must be developed not only for expanding fertilizer production but also for increasing biological nitrogen fixation". The new industrial technologies are today nowhere in sight.

Detailed studies of single farm case studies have shown nitrogen self-reliance to be possible. Wegryzn (1984) on a Pennsylvania mixed crop-livestock farm conducted 11 replicated field studies in 1979 and 1980 on corn following alfalfa in commerical fields of the Kutztown study farm with rates and sources of nitrogen as variables. There were no grain yield responses to supplemental nitrogen either as ammonium nitrate, leather dust or poultry manure. In general, supplemental nitrogen applications resulted in luxury consumption rather than increased yields. Soil nitrogen-supplying capabilities ranged from 111 to 249 kg nitrogen/ha over the 11 fields and averaged 166, 165, and 148 kg nitrogen/ha for first, second, and third year corn after alfalfa, respectively. Wegryzn stated that overall corn productivity was high, and, with refinement of the management system, could be increased. Nitrogen requirements for corn production could be supplied entirely by on-farm sources. "The avoidance of synthetic fertilizers, herbicides, and insecticides on this farm appeared to be incidental to high productivity, but no benefit could be seen altering this practice".

Patriquin (1981) indicated similar total nitrogen self-sufficiency for a Nova Scotia dairy farm. Patten (1982) found a cash crop wheat farm of 800 acres in Washington state to have had self-sufficiency in nitrogen since 1912. Many organic farmers growing field crops do not import nitrogen, but the cited studies are the only ones to document actual nitrogen status on organic farms where large amounts of animal feed were not being purchased and the nitrogen was coming largely from legumes.

A specific method used by many organic farmers to increase nitrogen fixation in their cropping systems is to overseed standing crops with legumes to start sod rotations or to give ground cover and nitrogen production during the fall and winter. This process of seeding legumes between rows of grain crops during the growing season or after harvest has much potential. It is also an example of research done by landgrant and USDA researchers which can contribute to both conventional and organic farmers. The amount of nitrogen fixed is heavily dependent on the amount of biomass produced in the early spring of the second year (usually the time prior to planting).

Researchers studied seeding methods, species, and amount of nitrogen contributed to the next crop, and method of killing the legume. Mitchell and Teel (1977) at the University of Delaware used the non-legume oats(*Avena sativa L*), and rye (*Secale cereale* L.) alone and in combination with legumes, hairy vetch (*Vicia villose* Roth), and crimson clover (*Trifolium incarnatum* L.) as nitrogen sources for corn. Total nitrogen in the biomass produced prior to killing by herbicides was quite small with only non-legumes, whereas inclusion of a legume increased the nitrogen in the biomass 3 to 4 fold, which was reflected in higher corn yields. Hairy vetch and crimson clover produced corn yields equivalent to 112 kg nitrogen/ha, the maximum rate used in this experiment.

Frye, et. al. (1982) at the University of Kentucky overseeded legumes into standing corn in mid-September by broadcasting seed on the surface or by drilling in the legume after corn harvest. Hairy vetch produced yields substantially above the other cover crops at Lexington, probably a result of the 3 to 4 fold increase in the biomass nitrogen (219 kg/ha). At Princeton, the yields were higher with hairy vetch or big flower vetch (Vicia grandiflora var. Kitzbeliana W. Koch) and provided nitrogen equivalent to 90 to 100 kg/ha of fertilizer nitrogen.

In a study on corn silage production by no-tillage and conventional tillage in New Jersey, Flannery (1981) reported 3-year average yields indicating that a hairy vetch crop provided nitrogen equivalent to between 135 and 200 kg/ha fertilizer nitrogen to corn silage. There was no corn yield response to the nitrogen applications where a hairy vetch cover crop was grown.

Based on work in North Carolina, Krenzer (1981) stated that legume cover crops of hairy vetch or crimson clover established during September in a conventionally-prepared seedbed provided 67 to 112 kg/ha available nitrogen to corn or grain sorghum. Work in Tennessee in 1980 and 1981 (Hargrove, 1982) indicated that the hairy vetch contributed biologically-fixed nitrogen to no-tillage corn equivalent to about 112 kg/ha fertilizer nitrogen.

Work by Jardine (personal communication) with overseeded legume cover crops in Maryland indicated that nitrogen produced in legume crops varied considerably. Nitrogen production in the biomass of hairy vetch was generally in the magnitude of 225 kg/ha. Overseeding legumes into soybeans is more difficult because of canopy light relationships; however, William H. Mitchell has established hairy vetch successfully by aerial application prior to leaf drop in soybeans. He studied several variables and found that management of the soybeans was the most important factor in establishing hairy vetch. (Crops and Soils, 1984). The use of legumes has many advantages; however, there are also problems. There are problems getting stands established, and the extra seed cost must be justified. In areas where moisture is limiting, the legume can reduce the available soil moisture, resulting in reduced yield and profit. In more northern areas, the requisite time required to produce biomass and therefore nitrogen may result in delayed planting of corn.

A recent article in The Furrow published by the John Deere Co., extolled the benefits of biological nitrogen as a cost-effective way of providing nitrogen (Gogerty, 1984). Several researchers' approaches to provided home grown nitrogen were cited, including Don Barnes, a USDA plant breeder at the University of Minnesota, who is looking for alfalfa (Medicago sativa L.) with a large root mass for heavy storage of nitrogen in the roots and superior ability to fix nitrogen right up until the ground freezes. He is attempting to develop varieties that can be seeded in the spring, cut twice for hay, and still produce 168 kg/ha of nitrogen per acre by November. Also cited was work by John Imsande, an Iowa State University geneticist, who is working on a way to include soybeans in continuous corn by interseeding a partial male sterile soybean line that fixes twice as much nitrogen as normal soybeans.

Nutrient-Cycling Efficiencies

There is growing evidence (some very circumstantial) that there are efficiencies of nutrient flow in organically-managed systems that are quantitatively different from those of conventional systems (Harwood, 1983).

A study of cash crop farms in the Palouse region of eastern Washington, one using organic methods and the other, conventional methods, shows similar results (Patten, 1982). These side-by-side farms were compared with respect to yield and soil characteristics for two years. The organic farm had not received fertilizer nutrient input since 1909. It used a winter wheat/spring pea (*Pisum sativum* L.)/Austrian winter pea (*Pisum sativum, pp, arvense* (L) Poir) (green manure) or summer fallow rotation. The conventional farm was under a winter wheat/spring pea rotation in which commerical nitrogen and phosphorus fertilizers were used. Soil test data, presented in Tables 1 and 2, show increasing levels for organic matter, extractable phosphorus and potassium for the organic farm when compared to the conventional farm. This suggestss an upward flow and accumulation of soil nutrients in the upper part of the soil horizon which is similar to natural soil-building processes. The downward movement and leaching of nutrients in the soil under conventional methods has had major implications in groundwater contamination by excess nutrients. The higher levels of extractable phosphorus on the organic farm is interesting as it was the conventional farm which received application of the phosphorus fertilizer.

Neither farm received potassium fertilizer; however, the organic farm had almost double the amount of extractable potassium compared to the conventional farm. All farmers reported about equal or greater historic yields than the local averages. Overall, the organic farm reported higher yields than those using conventional methods. Measured average yield (sum of two crops of wheat and one pea crop) were within 1 to 2% of each other when comparing organic and conventional fields. These yield comparisons, however, are difficult to make because they were in different fields on different farms. Input costs were substantially less on the organic farm and the environmental impact substantially reduced as a result of different in inputs. Rill erosion on the conventional sampling sites compared to the organic sampling sites was greater by a factor of 3.9, which indicates a significant difference in soil loss between the two systems.

Average long-term changes calculated in soil nitrogen and phosphorus pools resulted in substantial deficits of 44 and 14 kg/ha/yr, respectively on the organic farm and 23 and 5 kg/ha/yr for the conventional farm. However, nutrient deficits were not reflected in lower soil N and P levels in the plot areas tested on the organic farm, indicating that reduced soil erosion and greater efficiency of nutrient-cycling more than compensated for the outflow from crop harvest. These results indicate substantially better nutrient use efficiency. Bezdicek (personal communication, 1984) stated that they did not know where the nutrients came from in the organic system or where they went in the conventional system.

A replicated experiment in Nebraska (Sahs, personal communication) involved the following: A 4-year rotation using oats (Avena sativa L.)/red clover (Trifolium protense L.), corn, soybeans (Glycine max. L) and corn, with feedlot manure in place of N-P-K fertilizer. This set of treatments involves no insecticides or herbicides (classified as organic). The other extreme involved a regime of continuous corn with synthetic fertilizer, herbicides, and insecticides. Two additional treatments involved the first rotation but without insecticide or manure; with and without herbicide; and chemical N. Oats yielded about the same with all management systems (Table 3). Corn yield under organic management and continuous corn were identical over the eight years, with herbicide and fertilizer having a yield advantage of 9 bu/A. Soybean yields were slightly better with chemical input compared to the organic treatment.

The soil test data presented in Table 4 show that organic management resulted in substantially higher levels of soil phosphorus and potassium and somewhat higher organic matter, soil nitrogen and pH. This indicates that the organic yield potential may be increasing compared to the other regimes.

Table 1. Average[a] concentrations of organic matter, total N, total P, and extractable P of the 0-90 cm depths of an organic (O) and Conventional (C) summer fallow and winter wheat plot soils, from Fall, 1980 and Spring, 1981 sampling dates.

Soil Depth	Organic Matter		Total N		Total P		Extractable P	
	O	C	O	C	O	C	O	C
(cm)	----%----		----------------(ppm)----------------					
0-15	2.5	2.0+	1162	1029	598	600	8.9	6.6
15-30	1.8	1.4	910	758	546	530	6.2	2.9+
30-60	-	-	-	-	-	-	4.5	2.5
60-90	-	-	-	-	-	-	4.9	4.9
$LSD_{0.10}$ values[b]:	0.5		195		70		3.0	

[a] Values represent means of 15 replicates (6 from 1980, 9 from 1981) for OM and extractable P, and 21 replicates (6 from 1980, 15 from 1981) for TN and TP.

[b] Statistical analysis was performed on the top two depths for OM, TN, and TP, and on the top four depths for extractable P.

+Significance at 10% level.

Table 2. Average[a] concentrations of extractable K of the 0-180 cm depths in an organic (O) and conventional (C) summer fallow plot soil, Fall 1980.

Soil Depth	Extractable K O	 C
(cm)	-------(ppm)-----	
0 - 15	343	179*
15 - 30	248	165
30 - 60	145	137
60 - 90	92	89
90 - 120	67	61
120 - 150	52	60
150 - 180	43	61
$LSD_{0.05}$ values[b]:	104	

[a] Values represent means of six samples.

[b] Statistical analysis was performed at all depths for extractable K.

* Significance at 5% level.

Table 3. Crop yield as affected by management practice in Nebraska

	Oats[1]	Corn[2]	Soybeans[3]
Organic - Manure only	45	66	32
Herbicide and Fertilizer	45	75	36
Fertilizer only	44	72	35
Continuous Corn, Fertilizer, Insecticide and Herbicide		66	

[1] Average 1976, 1977, 1978, 1979, 1981, 1982, 1983

[2] Average 1976, 1977, 1978, 1979, 1980, 1981, 1982

[3] Average 1976, 1977, 1978, 1979, 1980, 1981, 1982

Table 4. Soil test values as affected by agricultural management practices in Nebraska. 1983.

	Organic Matter %			pH			Phosphorus (ppm)			Potassium (ppm)			Total Nitrogen		
	(0-6")	(0-8")		(0-6")	(0-8")		(0-6")	(0-8")		(0-6")	(0-8")		(0-6")	(0-8")	
	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982	1980	1981	1982
Organic	4.09	3.44	3.23	7.07	7.36	7.20	92	144	81	693	860	624	.20	.20	.13
Herbicide-Fertilizer	3.36	2.70	2.69	6.69	6.93	6.97	12	15	17	381	416	366	.17	.17	.15
Fertilizer only	3.44	2.74	2.62	6.93	7.22	6.96	15	14	17	375	386	345	.18	.17	.15
Continuous Corn	3.30	2.65	2.68	5.75	6.50	6.71	18	14	17	365	386	364	.17	.17	.14

Although limited, the research presented here attests to the success of this low-input production method. These technologies are feasible and they reduce costly inputs and erosion as well as environmental hazards. However, because of lack of research, there is insufficient understanding of how and why these systems work.

Bolton (1983) found on this same farm that there were no differences in numbers of soil microorganisms as determined by plate counts, but the alternative farm soil had significantly higher levels of urease, phosphates and dehydrogenase. On 2 of 3 sample dates the alternative soil had significantly higher microbial biomass.

Studies by Culik, et. al. (1983) indicated a long-term stability in soil test values on the Kutztown study farm in spite of a seeming nutrient deficit for the whole farm. Kaffka (1984) indicated similar results.

It is suspected that in organically-managed systems a higher proportion of organic matter breakdown may be caused by soil borne detritivores. Seasteadt and Crossley (1984) point to the important role of soil detritivores in mineralizing soil nitrogen, phosphorus and calcium. Mineralization rates were significantly higher where levels of collembola were higher. Michalak P.S.(1984.Summary of 1983 Colorado potato beetle research. Rodale Research Report. RRC/EN-84/5. In press), working at the Rodale Research Center, found collembola levels in an organically-managed field to be reduced by two thirds by application of a low-rate of ammonium nitrate fertilizer as compared to continued organic management. The significance of the effects of crop management on soil fauna in terms of nutrient cycling is not known. We continue to suspect that soil faunal differences account for some of the differences seen in movement of nutrients in soil and in release rates to the soil water solution.

Studies on the use of soil test to determine fertilizer needs have arisen from the above-cited work on nutrient use efficiency.

The high cost of petrochemical fertilizers as well as health and environmental concerns over nitrate contamination of groundwater and phosphates in surface water supplied have increased concern about the amounts of synthetic nitrogen used in agricultural production. When Rodale researchers and others (DeVault, 1982; Liebhardt, 1982 and 1983; Liebhardt and Culik, 1983; and Olson, 1982) raised the issue of fertilizer recommendations in a study of soil test laboratories, the work was welcomed by many scientists, at least in personal communication.

Land grant university soil testing laboratory comparisons in Nebraska, Kansas, Colorado, South Dakota and Minnesota and long-term studies between the TVA and land-grant institutions in 10 states show that soils already high to very high in phosphorus and potassium do not respond positively to further additions. Collectively, this research shows over-recommendation of nitrogen, phosphorus and potassium in most of the major cropping areas of the U.S. by soil testing laboratories. This information is beginning to change the thinking of the people that operate and use soil testing services. The estimated savings from reduced fertilizer could be as high as 20 to 50% of the $8 to 9 billion presently spent for fertilizer with no reduction in crop yield.

Soil Erosion

It has been suggested that organic farms appear to have noticeably less soil erosion (Papendick, et al. 1980). Patten (1982) found in her comparison farms an erosion rate estimated from rill measurement of 8.2 mt/ha on the organic and 32.2 mt/ha on the conventional farms. Calculated differences based on the universal soil loss equation were 6.2/1. It seemed probable that the soil was less erosive on the organic farm (suggesting more rapid water infiltration) than did conventionally farmed soil. In the Kutztown farm study, Culik reported a calculated average of 10.1 tons/ha/year on the study farm. A hypothetical conventional contour-cropped conventional farm would have 20.0 tons/ha/year loss, about equal to the average soil loss in corn fields of the county where the study was done. Sampson (1981) claims that organic agriculture could significantly reduce the nations soil erosion problem. This reduced erosion appears to be a critical element of the nutrient cycling efficiency of many organic farms.

Problems of Conversion

It is universally agreed that farmers experience a 3 to 5 year problem of conversion from conventional to organic farming (Papendick et al., 1980). We feel that the conversion process involves changes in nutrient flow within the soil which are extremely complex. Research on this phenomena are needed for a better understanding of nutrient uptake and loss results. In addition, these studies of whole farms, even though clinical in nature, show that detailed studies of wholistic systems are needed for both conventional and organic systems.

Trials at the Rodale Research Center have been running since 1981 to determine crop yields when land which had been farmed previously under a conventional farming system was converted to organic management. In this experiment, two organic systems and a conventional system are being compared with respect to crop yield. This site in eastern Pennsylvania showed that available soil nitrogen and weeds were the major problems in the first year of this conversion. Starting the conversion process with a small grain-legume mixture or with soybeans has been best. Oat yield was high and soybeans yielded the same in both organic and conventional systems. Corn production the first 2 years was reduced about 40% under the organic regime because of nitrogen deficiency and weed pressure. However, by the third year, organic corn yield was about 90% of conventional corn, as weeds were brought under control and available soil nitrogen increased through the use of legumes and manure. Production expenses were considerably less in the organic system since it relies on crop interactions in the rotation rather than on continually off-farm inputs.

This multidisciplinary research is being conducted with the cooperation of USDA, University of Nebraska and University of California - Berkley researchers. It suggests that multi-disciplinary conversion experiments using different cropping systems and sites would be helpful to understanding the complexities of both systems.

Insect Pest Management

Despite the current application of approximately 450,000 metric tons of pesticides in U.S. agriculture, insect pests, plant pathogens, and weeds destroy more than a third of all potential crop production (Pimental, 1981). Crop losses due to insects have increased nearly 2 fold (from 7 to 13%) from the 1940s to the present, in spite of a more than 10 fold increase in insecticide use (Pimental, et al (1978).

Organism resistance to pesticides is also becoming a major problem. Georghiou (1980) documented that 432 species of arthropods, 50 species of plant pathogens, 5 species of weeds, and 2 species of nematodes have become resistant to one or more chemicals. Of the resistant arthropods, 60% are injurious to agriculture and 40% are pests or vectors of disease of man and other animals. The use of pesticides is also causing serious environmental and public health problems (Pimental, et al (1982). An estimated 45,000 human pesticide poisonings occur annually, with about 3,000 hospitalizations and 200 fatalities (EPA, 1974; Pimental, et al, 1980). Of all the hazards reported in food, by far the greatest fear of consumers (77%) is a result of residues of pesticides and herbicides. This was a result of a survey in January of 1984 and reported by Timothy Hammonds of the Food Marketing Institute (Allentown and Lehigh Morning Call. March 27, 1984, p.7).

Motyka and Edens (1984) over a 2 year period studied paired organic and conventional farms growing commercial onions. These were compared with "control" sites having neither the conventional sprays nor the biological "structuring" of the organic sites.

"Agricultural systems typically rely on chemical inputs to maintain the 'balance'. Obviously, the control site had neither the buffering capacity nor the chemical inputs and, therefore, fluctuated wildly. The organic site, also free of chemical inputs, contained a highly structured system of organisms that maintained a balance between pests and beneficials. Although the high-input sites were sprayed to decrease population levels, this artificial check system was not as effective as the natural buffer of the organic systems". The conventional farmers used repeated sprays of Sevin, parathion, diazinon and malathion, and experienced, for much of the season higher levels of onion fly than did the organic farmers. It has been claimed by many practitioners of organic agriculture that they experienced fewer pest problems, but this is the first hard evidence, taken from a very pest-susceptible crop, that such was the case.

Dahlsten (1983) who studied insects under three different habitats says: "Through millions of years of evolutionary development, insects have permeated the diverse and essential natural processes that make much of the world work as a self-sustaining biological system". In each of the 3 cases, Wiggins (1983) says, chemical insecticides and other pesticides may be playing a major role in a very complex biological system. Citing the great diversity of aquatic insects in freshwater habitats, he shows evidence that pesticides disrupt the aquatic ecosystems. Second, he cites soil fauna, where there may be as many as a million arthropods per square meter, and microorganisms such as bacteria and fungi. Soil flora and fauna have barely been studied and little is known of the roles that various organisms play in nutrient cycling, crop fertility, and soil tilth. The third example is the predator/prey and parasite/host relationships, where more is known of the interactions within these systems. Pesticides used on these systems have caused resurgence and secondary pest outbreaks. Much needs to be known about these important groups of insects, yet the necessary basic research is not well-funded.

Much work supports these concepts. For example, Baker (1982) indicates that insecticides have created environments which favor the development of resistance in many species resulting in decreased genetic variability of the species. Pimental and Edwards (1982) state that natural biota perform many essential functions such as degrading organic wastes, clearing water and soil of chemical pollutants such as pesticides, recycle vital chemical elements within the ecosystems, producing biotic nitrogen, and conserving soil and water. Pesticides can influence these essential functions by reducing specie diversity and modifying food chains; changing patterns of energy flow and nutrient cycling (including nitrogen); reducing soil, water and air quality; and changing the stability and resilience of ecosystems (Seasteadt and Crossley, 1982).

We do not yet know the effects of many of our farming practices on pest populations. For example, 2-4-D treated corn leaves in one comparison had higher nitrogen content, resulting in a 3 fold increase in corn leaf aphids (Oka and Pimentel, 1974). In addition, corn was more susceptible to corn borer attack and females were larger and laid more eggs.

Insect-Repellant Plants

It has long been held by organic practitioners that certain aromatic herbs repelled insects. Screening trials at the Rodale Research Center have sorted through several dozen herbs reported to have insect-repellant properties.

Work done by Matthews (1982 and 1984) at the Center has shown potential for the control of Colorado potato beetles (*Leptinotarsa decemlineata* (Say)) by using interplants of tansy (*Tanacetum vulgare* (L.):compositae) or a water extract from the tansy itself. The extract or the tansy appear to be feeding deterrents to the beetles so they avoid the area or eat very little of the sprayed potato foliage. It was shown that camphor was one constitutent of tansy having major insect repellant activity.

Other work done by Matthews (1984) has shown different intercrop "living mulch" species to have significant effects on numbers of flea beetle (*Phyllotreta striolata* and *P. cruciferae*) on cabbage.

Natural ways of controlling pests appear to be promising for the future. An anti-juvenile extract from a common bedding plant, *Ageratum houstonianum* was prepared which induced precocious metamorphosis in insects shortening the life cycle of the immature stages (Bowers, et al, 1976). In addition, most males and all females were sterile. This work could lead to the development of safe insect-specific pesticides. A viral insecticide which controls cotton bollworms and budworms and the same insects on corn, soybeans, sorghum and tomatoes has been approved for use (Enlow, 1984). Carlo M. Agnoffo, director of ARS Biological Control of Insect Laboratory. said the insecticide is specific against Heliothis insects that damage 9 field crops, 13 vegetable crops, 4 fruit crops as well as hemp, peppermint, pines, poppy and tobacco.

These findings, with further research, could lead to significant breakthroughs in identifying compounds useful in integrated pest management schemes. Several comprehensive reviews of the potential use of plant derived materials for insecticides, insect repellants and attractants have been done (Jacobson, 1983). There would appear to be significant potential for isolation or identification of naturally occurring substances which could be of use in modifying insect behavior.

Allelopathy

Organic farmers have long known of the effects of cover crops in rotation on weed community modification. The effects of sorghum or sorghum-sudan crops on nutsedge suppression and of flax in rotation on mustard are a part of organic folklore. There have been several excellent recent reviews of the relevance of allelopathy to agriculture (Putnam, 1978; Newman, 1982 and Putnum, 1983). Putnam (1983) has demonstrated that residues of crops which contain phytotoxins can be effectively used to inhibit germination of sensitive species. These leads could open countless new avenues for identification of naturally-occurring crop resistances for us in weed management programs.

Disease - Suppressive Soils

Supporters of alternative methods of agriculture in the Netherlands claim that organic manures stimulate the "antiphytopathogenic potential of the soil" in addition to providing nutrients for the plants (Boeringa, 1980). Hornby (1983) has reviewed suppressiveness in soils. Some incidences are reported to occur in continous cropping of a single species. Other incidences are known to occur through manuring and attainment of species diversity in the soil. It is felt that in many cases organic-like management of the soil leads to suppressiveness or stability of soil-borne disease organisms. There is considerable interest in this area among plant pathclogists (Schroth and Hancock, 1982).

Understanding the basis for this natural disease suppression could lead to improved plant health. Some forms of disease suppression may be caused by bacteria, pseudomonas which agressively colonize root surfaces. Increased plant growth and yield are closely associated with the capacity of some of the bacteria to produce iron binding compounds called siderophores. The hope is to identify the microbes for suppressiveness and to harness them as biological control agents.

Summary of Organic Agriculture-Related Technologies with Potential for Further Use

1. The integration of a multitude of practices in organic systems results in lower input costs and lower energy inputs in farm practice. Purposeful structuring of the system is required.
2. Nitrogen self-reliance is possible in field crop systems.
3. Nutrient cycling efficiencies seem pronounced under organic field crop management.
4. Soil test and nutrient need assessment practices require modification.
5. Soil erosion can be controlled through organic management; however, proper management in a conventional system will also work.
6. Problems of conversion from conventional to organic or lower input systems seem nutrient-related.
7. Several new insect management strategies and technologies are indicated from organic practice and research.
8. Allelopathy could be a useful weed management tool.
9. Disease-suppressive soil management may be possible.

Institutional Changes Needed:

The Need for a Broadened Research Paradigm

Edens (1982) argues for the eventual need for "closed system agriculture if our systems are to ever become sustainable. To develop such systems he calls for a broadened research approach.

"Disciplinary researchers seldom confront boundary issues. The area of interest to a disciplinary research scientist is assumed to be well defined by the class of phenomena under investigation. Research progresses in a stepwise fashion from phenomena identification to causality. The phenomena under investigation define the system boundaries, which results in a reductionist approach to problem solving that is well suited to disciplinary research activities.

Using systems science as an analytical construct, it is possible to reverse the process from observed phenomena to higher level concerns. The systems boundary must be well defined and explicitly understood if effective communication is to be maintained".

Agriculture is an integrated system of knowledge and technologies and must be dealt with in this fashion. A more wholistic approach to research of both conventional and organic systems is needed for any major breakthrough. Much of this needed research falls between departmental lines or subject matter areas. As we have seen, reductionist research results in many undetected problems for the producer, as well as the consumer and the environment.

Reductionist approaches to research in the areas of soil fertility and pest control, for example, have led to excessive nutrient run off and leaching, resistant species of insects, environmental contamination and unbalanced production systems which have significant social and economic costs. If use of inputs is disrupting these systems, we need to know the effect on nutrient cycling and availability, and organism disruption resulting in pest problems.

In many cases, linkages between disciplines need to be forged so that specialists can integrate their work on projects. In landgrant institutions, there are regional research projects which inter-connect research across geographical areas. This model has often been quite successful, yet a way of integrating work on the same campus appears necessary to bridge the gap which now exists. Both researchers and administrators need to work at improving this situation so that the reward system recognizes inter-disciplinary work.

In many cases, this will mean a realignment of research priorities since there may be not increase in total funding. The research structure may have to be changed significantly to account for the wholistic nature of the system. In many cases, real efficiencies will be achieved because investigators working on the same experimental area or subject can reduce redundance. In other cases, increased funding will be necessary. More work is needed to develop rotations which are efficient with respect to production. In the past (1950 - 1975) yield benefits of rotations were overlooked and almost forgotten, as it appeared the chemical fertilizers, herbicides and insecticides could be used as a substitute for rotation (Crookston, 1984). Research evidence now shows that in spite of all the management inputs a farmer might impose, there was still a yield advantage to be obtained from rotations.

Biocides which result from a basic knowledge of how organisms function are needed. Examples are allelopathic chemicals, anti-juvenile compounds with insects and organisms which suppress diseases in soil. Development of these types of technologies would appear to be major breakthrough since these natural products would be much more specific than broad spectrum pesticides. Breeding disease and insect resistant plants is another approach which should continue. Resistance to sub-optimal conditions is another plant characteristic needed, as it is less expensive to change the plant than the soil in many instances.

Tillage now has a major impact on the erosivity of soils. Conservation tillage is a relatively effective technique in reducing erosion, but, at present, it is a pesticide-intensive system. Use of allelopathic and crop management principles could result in conservation tillage less dependent on these biocides. Little work is taking place on such systems.

In summary, what is needed are some structural changes in our approach to both conventional and organic systems so that wholistic information about both systems becomes available to researchers, farmers, and consumers.

Likely Timing of Commercial Introduction

The completion of various lines of research for commercial adoption depends on the line of research, institutional arrangements, economics, and environmental considerations. At present, economic and environmental factors are rapidly pushing farmers to produce food which requires less inputs and does not impact on the environment. Consumers want food which is not adultered. Although these groups do not produce new technologies, their demands put pressure on those who do develop the technologies.

Research on conservation tillage and overseeding of legumes is now on line. Although it needs further development, it should be well-developed by 1990 with continuing support. Work on the benefits of rotations appears to be at the same stage of development, but it is a much more complex technology and will take five to ten years or more to develop, although much information will become available by 1990 with continuing support.

Work on natural products which could be used to control pests are starting to appear on the market. Undoubtedly, much is in the developmental stage at this point by commercial and research organizations. In a short time (5 years), many more of these products will be appearing on the market. In the long term (10-20 years) these types of products will probably dominate the market because they will be less disruptive to natural systems and are safe for users, consumers, and the environment. As the component parts of these individual technologies become better known, integration of systems into a wholistic approach will be more feasible. However, integrated studies should be initiated now to provide a better understanding of both organic and conventional systems. Within a 5 to 10 year period, much could be learned by this approach.

Potential Impacts

The previous sections pointed to current economic and environmental concerns which have been making organic agricultural approaches appealing to the mainstream practitioner. Should the lines of research now being developed be pursued on a broad scale, be extensive and integrated, there is evidence that agricultural production in this country could:

- Increase the use of cultural and biological practices to grow crops

- Substantially reduce the need for synthetic chemical pesticides and fertilizers with corresponding reductions in environmental and health risks, input costs, and soil erosion.

Field crops such as corn, wheat, oats, rye, barley, soybeans, and forage crops such as legumes, and grasses are the major U.S. crops, comprising 80-85% of U.S. cropland. Obviously any production system which substantially reduces or eliminates chemical pesticides and fertilizers on these agronomic crops would have a significant effect on farmers, consumers and the agribusiness sector.

If farmers shifted to organic production, farms would be more diverse biologically and economically. This would provide a more stable enterprise as their survival would not ride on one or two cash crops. With an increase in farms' economic stability, the small farm could remain economically competitive and ensure diverse, competitive food production systems.

REFERENCES

1. Baker, John (1982). Selective effects of insecticides on within-species variation: The lessons to be learned when considering the environmental effects of pollutants. Agriculture and Environment, 7:187-198.

2. Boeringa, R. (ed.) 1980. Alternative methods of agriculture. Developments in agricultural and managed-forest ecology. 10. Esevier Scientific Pub. Co., Amsterdam. 199p.

3. Bolton, H. Jr. 1983. Soil microbial biomass and selected soil enzyme activities on an alternatively and a conventionally-managed farm. M.S. thesis (unpublished). Washington State University, Pullman, WA.

4. Bowers, William S., Tomishisa Ohta, Jeanne S. Clere, Patricia A. Marsella (1976). Discovery of insect anti juvenile hormones in plants. Science. 193:532-547.

5. Burgess, B.K. 1983. Nitrogen fixation: Research Imperatives in: Lu, Y. ed. Emerging technologies in Agricultural Production. USDA. 152 p.

6. Crookston, Kent R. 1984. The rotation-effect. What causes it to boost yield. Crops and Soils. March 36 (6):12-14.

7. Crops and Soils, March 1984. 36(6):19-20.

8. Culik, M.N., J.C. McAllister, M.C. Palada and S.L. Rieger. 1983. The Kutztown Farm Report. Rodale Research Center. Kutztown, PA.

9. Cunningham, E.A. 1982. Organic farming in eastern Nebraska. M.S. thesis (unpublished). University of Nebraska, Lincoln, NE.

10. Dahlsten, Donald L. 1983. "Pesticides in an Era of Integrated Pest Management." Environ. 25:45-54.

11. DeVault, George. 1982. "Testing, Testing. . ." Series of five articles in The New Farm.

12. Edens, T.C. and D.L. Haynes. 1982. Closed system agriculture: Resource Constraints, Management Options and Design Alternatives. Ann. Rev. Phytopath. 1982. 20:363-85.

13. Enlow, Robert E. 1984. January. Microbial insecticides. Finding insects weaknesses. Agr. Res. J. 32(5)12-13.

14. EPA. 1974. Strategy of the Environmental Protection Agency for Controlling the Adverse Effects of Pesticides. Office of Pesticide Programs, Environmental Protection Agency, Washington, D.C.

15. Flannery, R.L. 1981. Conventional vs. no-tillage corn silage production. Better Crops. LXVI (Summer-Fall): 3-6.

16. Frye, W.W., J.H. Herbek and R.L. Blevins. 1982. Legume cover crops in production of no-tillage corn in environmentally-sound agriculture. ed. Wm. Lockeretz. Praeger Pub., New York, NY.

17. Geisler, C.C., J.T. Covan, M.R. Hatlery and H.M. Jacobs. 1980. Sustained land productivity: equity consequences of technological alternatives. Report prepared for the U.S. Congress, Office of Technology Assessment, as part of an assessment entitled "Impact of Technology on Productivity of the Land."

18. Georghiou, D.P. 1980. Implications of the development of resistance to pesticides: Basic principles and consideration of counter measures in Pests and Pest Management in the Carribean: Procedings of a Seminar and Workshop, Barbados, Nov. 3-7. E.G.B. Gooding, ed., p. 116-129.

19. Gogerty, Rex. 1984. "Home Grown Nitrogen." The Furrow. Jan/Feb.

20. Hargrove, William L. (ed.). 1982. Proceedings of the mini-symposium on legume cover crops for conservation tillage production systems. Athens, GA: Univ. of Georgia Spec. Pub. 19.

21. Harwood, R. 1983. International overview of regenerative agriculture. in: Semoka, J., F. Shao, R. Harwood and W. Liebhardt (eds). Proceedings of workshop on resource-efficient farming methods for Tanzania. Rodale Press, Inc., Emmaus, PA 128 p.

22. Harwood, R. 1984. Organic farming research at the Rodale Research Center. in: Bezdicek, D.F. ed. Organic Farming: Current Technology and its Role in Sustainable Agriculture. American Society of Agronomy (in press).

23. Hornby, D. 1983. Suppressive Soils. Ann. Rev. Phytopathol. 21:65-85.

24. Jacobson, M. 1983. Insecticides, insect repellants, and attractants from arid/semiarid land plants. in: Plants: The Potentials for Extracting Protein, Medicines and Other Useful Chemicals. Office of Technology Assessment. 252 p. Jacobson, M. and Crosby, D.G. (eds.), Naturally Occurring Insecticides. New York: Dekker, 1971.

25. Kraten, S.L. 1979. A preliminary examination of the economic performance and energy intensiveness on organic and conventional small grain farms in the Northwest. M.S. thesis, (unpublished), Washington State Univ., Pullman, WA.

26. Krenzer, E.G., Jr. 1981. Cover Crops and Cover Crop Management. Paper presented at Southeastern No-Till Systems Conf. No. 24, 1981, N.C. State Univ., Raleigh, N.C.

27. Liebhardt, William C. 1982. Other tools put soil tests in perspective. The New Farm. Sept./Oct.

28. Liebhardt, William C. 1983. Viability of fertilizer recommendations by soil testing laboratories in the United States. in: Environmentally Sound Agriculture. ed. William Lockeretz.

29. Liebhardt, William C. and Martin Culik. 1983. How to lose $42. an acre. The New Farm. February.

30. Lockeretz, William, Georgia Shearer, Susan Sweeney, George Kuepper, Diane Wennu and Danial Kohl. 1980. Maize yields and soil nutrient levels with and without pesticides and standard commercial fertilizers. Agron. J. 72: 65-72.

31. Lockeretz, William, Georgia Shearer and Daniel H. Kohl. 1981. Farming in the corn belt. Sci. 211:540-546.

32. Matthews, D. 1982. The effects of interplanting with catnip and tansy on insect pest populations on potatoes, peppers and squash. Rodale Research Report. RRC/EN-82/3.

33. Matthews, D. 1984. Summary of 1983 Colorado potato beetle research. Rodale Research Report. RRC/EN-84/5. (in press)

34. Michalak, P.S. 1984. Comparative analysis of collembola associated with organic and conventional agroecosystems. M.S. thesis (unpublished). Michigan State Univ.

35. Mitchell, W.H. and M.R. Teel. 1977. Winter annual cover crops for no-tillage corn production. Agron. J. 69:569-572.

36. Motyka, G. and T.C. Edens. 1984. A comparison of heterogenity and abundance of pests and beneficials across a spectrum of chemical and cultural controls. Report on EPA Grant #806065. Michigan State Univ., E. Lansing, MI.

37. Newman, E.I. 1982. The possible relevance of allelopathy to agriculture. Pestic. Sci. 13:575-582.

38. Oka, I.N. and D. Pimentel. 1974. Corn susceptibility to corn leaf aphids and common corn and smut after herbicide treatments. Environ. Entomol. 3:911-915.

39. Olson, R.A., K.D. Frank, P.H. Grabouski and G.W. Rehm, 1982. Economic and agronomic impacts of varied philosophies of soil testing. Agron. J. 74. 492-499.

40. Papendick, R.I., L.L. Boersma, D. Colacicco, J.M. Kla, C.A. Kraezle, P.B. Marsh, A.S. Newman, J.F. Parr, J.B. Swan and I.G. Youngberg. 1980. Report and recommendations on organic farming. Sci. and Educ. Admin., USDA Beltsville, MD 94 p.

41. Patriquin, D., D. Burton and N. Hill. 1981. Strategies for achieving self-sufficiency in nitrogen on a mixed farm in eastern Canada based on the use of the faba bean. p. 651-671 in: Lyons J., R. Valentine, D. Phillips, D. Rains and R. Huffaker (eds.) Genetic engineering of symbiotic nitrogen fixation and conservation of fixed nitrogen. Plenum, NY.

42. Patten, Andrea. 1982. Comparison of nitrogen and phosphorus flow on an organic and conventional farm. M.S. thesis (unpublished), Dept. of Ag. and Soils. Washington State Univ.

43. Pimentel, David and Clive A. Edwards. 1982. Pesticides and ecosystems. Bioscience 32:595-600.

44. Pimentel, D., J. Krummel, D. Gallahan, J. Hough, A. Merrill, I. Schreiner, P. Vittum, F. Koziol, E. Back, D. Yen, and S. Fiance. 1978. Benefits and costs of pesticide use in U.S. food production. BioScience 28:772, 778-784.

45. Pimentel, David, Carol Glenister, Sarah Fast and David Gallahan. 1982. An environmental risk assessment of biological and cultural controls for organic agriculture in environmentally sound agriculture. ed. Wm. Locketetz. Praeger Pub., New York, NY.

46. Pimentel, D., D. Andow, R. Dyson-Hudson, D. Gallahan, S. Jacobson, M. Irish, S. Kroop, A. Moss, I. Schreiner, M. Shepard, T. Thompson, and B. Vinzant. 1980. Environmental and social costs of pesticides: A preliminary assessment. Oikos 34:125-140.

47. Pimentel, David, Gigi Berardi and Sarah Fast. 1983. Energy Efficiency of farming systems: Organic and conventional agriculture. Agro. Ecosys. and Envir. 9:359-372.

48. Pimentel, D. 1981. Handbook of pest management in agriculture. Vols. 1-3. Boca Raton, Fla: CRC Press.

49. Putman, Alan R., Allelopathic chemicals. 1983. Chem. and Eng. News. April 4. 34-35.

50. Putnam, A.R. and J. DeFrank. 1983. Use of phytotoxic plant residues for selective weed control. Crop Protection. 2(2), 173-181.

51. Roberts, K.J., F. Warnken and K.C. Schnecberger. 1979. The economics of organic crop production in the western corn belt. Dept. of Ag. Ec. paper #1979-6. Univ. of Missouri, Columbia, MO.

52. Sampson, R. Neil. 1981. Farmland or Wasteland. Rodale Press, Inc. Emmaus, PA.

53. Schroth, Milton N. and Joseph G. Hancock. 1982. Disease-suppressive soil and root-colonizing bacteria. Science. 216:1376-1381.

54. Seastedth, T.R. and D.A. Crossley, Jr. 1984. The influence of arthropods on ecosystems. Bioscience 34(3):157-161.

55. Wegrzyn, Victor A. 1984. Nitrogen fertility management in corn -- a case study on a mixed crop-livestock farm in Pennsylvania. Ph.D. thesis (unpublished). PA State Univ.

56. Wiggins, G.B. 1983. Entomology and Society. Bul. Entomol. Soc. Amer. Spring. 27-29.

Background Paper No. 22

Communication and Information Management

Battelle Columbus Laboratories
Columbus, Ohio

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

TABLE OF CONTENTS

Page

INTRODUCTION 1

CURRENT STATE-OF-THE-ART 2

Local Communication Networks 2

Data Terminals 3

Software Systems 5

EXAMPLES OF COMMUNICATION AND INFORMATION MANAGEMENT IN AGRICULTURE 8

TECHNOLOGICAL BREAKTHROUGHS NEEDED 9

Timing to Commercialization. 13

INSTITUTIONAL ARRANGEMENTS. 14

MAJOR IMPACTS 15

REFERENCES 20

LIST OF TABLES

Table 1. Selected Examples of Agricultural Information Systems 10

LIST OF FIGURES

Figure 1. Diagram of Conceptual Integrated Farm Management Information System 17

SUMMARY OF COMMUNICATIONS AND INFORMATION MANAGEMENT

This paper discusses the technologies being applied to agricultural on-site communications and information management. The important technologies influencing communications and information management are local communications networks, data terminals, software database systems, manufacturing management systems and expert systems.

Local communications networks include private business exchanges (PBXs) and local area networks (LANs). The major trend in these systems is an increasing capability to integrate multiple devices and multiple services, such as voice and data.

Data terminals are equipped to input data and provide readout capability for computer operations. Data terminals are used to monitor and control batch operations. The trends have been toward increasing computer power at the terminal and toward linking data terminals to sensors and controls to link production management to monitoring and control.

Software systems can be categorized into three major categories applicable to agricultural problems - financial analysis, database management, and applications specific software. Major trends have been directed toward solving on-farm management problems. Two specific types of applications oriented software that may be applied to agriculture are manufacturing management software and expert systems. Manufacturing management systems are used to plan and schedule activities, while expert systems are aimed at problem solving and specific fields of expertise.

With new communications and information management systems it becomes possible for farmers to access information databases from remote locations. Databases such as CRIS or AGNET provide access for farmers to solve management problems. Experimental systems dealing with electronic trading of cattle and hogs show increasing emphasis on the use of electronics in marketing.

The most important breakthrough necessary for increasing the use of on-farm communications and information management systems is a method to stimulate farmers to learn to use and apply information management techniques in their operations. Presently many farmers lack the technical programming experience and expertise needed to develop the complex software necessary for integrating components of the information management systems for on-farm use. This programming void could be filled either by private firms, colleges, universities or extension services.

A major impact of farmers using communications and information technologies will be increased information available for managerial decision making. The ability to integrate the microdata from the farm with the macrodata of external databases will enable farmers to plan more effectively. There will be an increased demand by farmers for workshops, seminars and courses dealing with computer use, information management, problem solving and on-line computer techniques. Presently extension services and universities are attempting to fill these voids. For farmers willing to invest the time for self education or continuing education to learn and understand how to incorporate communications and information management techniques into their operations, the rewards will be increased profits, efficient resource use and effective management of their agricultural endeavors.

COMMUNICATIONS AND INFORMATION MANAGEMENT

Introduction

One critical component for effective and efficient farm management is timely information about past, current, and planned farm operations and activities. This paper will discuss technologies which are being applied, or could be applied, to agricultural on-site communications and information management. Foremost among these technologies are:

- Local communications networks
- Data terminals
- Software and database systems
- Manufacturing management systems
- Expert systems.

Application of any or all of these technologies would aid the farmer in activities, such as ordering supplies, budgeting and accounting, and analyzing crop yields and livestock production efficiency.

Major trends in communications and information management presently include:

- Modularity of software packages and computing equipment, which implies that:
    - Each package is designed for a specific application (budgeting, accounting, order supplies)
    - Each package can stand alone

  - Each package can be integrated with other packages (marrying budgeting and accounting with order planning)
- Distributing computing equipment to the point of application, for example, in the dairy barn or in the fields, through the use of low-cost VLSI (very large-scale integrated circuit) components
- Integrating local communications and information management with other services such as sensors or telecommunications

During the next two decades the continued development of these trends will result in systems that will impact agriculture greatly. To assess the potential impact of these trends this paper will begin with a discussion of the current state-of-the-art for each earlier listed technology.

Current State-of-the-Art

The communication and information management technologies deemed most important have been divided into three major categories. Each is discussed separately.

Local Communication Networks

Local communication networks available today include private business exchanges (PBXs) and local area networks (LANs). PBXs were first developed for interoffice telephone networks and are a subset of LAN technology. PBXs are available for voice-only, data-only communications or for both voice and data.

LANs were developed from computer technology and are for data-only. Data PBXs and LANs both can process information from multiple-types of hardware, such as bar code readers, word processors or personal computers if each hardware device is interfaced to the network.[1] LANs generally have much higher rates of data transfer than PBXs, but are frequently more costly.

The major trend in local communication networks is an increasing capability to integrate multiple devices and multiple services, for example, voice and data. Other trends include increased standardization and increased capability to reduce costs.

The major problems with local communication networks for farming are (possibly) excessive cost of the network and difficulties with interfacing different types and brands of devices (i.e., data terminals) to the network.

Data Terminals

Data terminals are used for manual input of data to computer systems. Data terminals generally are equipped with one or two of three basic types of data acquisition devices: bar code readers; card readers; and keyboards. Readout capability can be provided by LED (light emitting diode) or CRT (cathode ray tube) high-speed displays or by hard-copy printers. Data terminals generally are used to monitor and control batch production operations, as opposed to sensors, that monitor systems in real time. For example a batch operation on the farm could be the delivery of feed components for formulating rations or the preparation and planting of a field. Monitoring and control of process type operations is described in the Monitoring and Control papers. Data terminals are useful only if linked to a management and control system through a communication network.

---

[1] Interfacing requires a physical connection and specialized software which may involve considerable expertise by the user.

Trends in data terminals are toward increased computing power at the terminal and toward linking data terminals to sensors and controls (to link production management to monitoring and control).

Problems. Major problems with low cost data terminals are that they are not user friendly, require training for the operator, and are not extremely flexible. These problems are due to lack of computer power at the terminal, which prohibits the use of complex software required to drive graphics display and interogate the operator. Data terminals which provide large displays, feedback to the operator, and are easy to use, are more costly, less rugged and not easily adapted to the on-farm environment.

An additional problem is that data terminals and process controllers are usually separate items, so connecting data terminals and process controllers into a single network can be troublesome, due to lack of standards for communication. This incompatibility between data terminals and controllers results in the need for two control systems - one for equipment and one for production management.

Software Systems

Three major categories of software which are applicable to agriculture are: financial analysis software, database management software, and application-specific software. Financial analysis software facilitates standard accounting procedures, such as general ledger, accounts receivable, accounts payable, payroll, and spread sheet analysis. These packages are applicable to any type of business, including agriculture. Financial analysis software, which can be used on personal computers, is the most effective of the presently available software in farm management applications.

Database management software (DBMS) is designed to simplify computer information management. DBMS is used to manipulate data stored by the computer, for example, in the computer memory, on flexible magnetic discs, or a cassette tape. Using DBMS, a novice can set up storage files, store data, and perform other operations, such as transfer data, copy data, rename files, and merge files. As with financial analysis software, certain DBMS packages are made for personal computers.

Specific applications software has been developed to provide direction or advice for decision-making concerning a specific problem. If provided with data from a specific problem situation (application), the applications software will provide a method or approach for solving the problem. Examples of specific applications software for agricultural problems include:

- Ration formulation
- Crop fertilizer purchase

- Herbicide selection
- Grain sale selection
- Livestock breeding (Brook, 1982).

Specific applications software can be accessed over several agricultural information service networks, such as AGNET, ANSER, FACTS, and TELPLAN, or can be custom-designed for a specific farmer.

Major problems with specific applications software are its relatively high cost and low flexibility. Additionally, a long development time is frequently required to code, debug, and validate software for any specific application.

Two categories of specific applications software which could be applied to agriculture are Manufacturing Management Systems (MMS) and Expert Systems. These are discussed below.

Manufacturing Management Systems. Manufacturing management systems (MMSs) are used to plan and schedule activities in a factory situation, but appear to have considerable applications for agriculture. Current MMSs generally are built from modular software components and geared to specific applications, such as:

- Inventory management
- Material requirements planning
- Capacity planning
- Material control
- Purchasing.

Closed-loop MMSs are tied to shop floor data terminals, so that planning and re-planning can be performed as timely data is received and processed. Because MMSs most often are designed for general production systems it appears the technology could be applied to farm management with minimal changes. However, a great deal of effort is required to apply a general MMS module to any specific production facility, for example, to a specific farm situation.

MMS software is available for mainframe computers, minicomputers, and personal computers. Trends in MMS are toward greater modularity, easier adaptability of software by the user, more user-friendliness, and toward more realistic modeling of production systems using dynamic simulation.

Expert Systems. Expert systems are software packages aimed at problem-solving in specific fields of expertise. The most popular application of these systems to date has been in human health-related diagnosis problems and in oil well log data analysis (configuration and trouble shooting of complex systems). However, expert systems are being developed for animal disease diagnosis and equipment failure diagnosis. Expert systems (can be developed for any specific problem), for example, farm management decision making. However, high development costs and long lead times currently are required to develop expert systems. The most important components of an expert system are:

- The ability to conduct a dialogue in the language of user (farmer)
- Access to well accepted data and logic from the field in question (agriculture)
- The ability to learn from past decisions.

However, current expert systems are not extremely strong in any of these components.

Current development work in expert systems is aimed at improving the general software capable of logic and self teaching. Fundamental advances will be required to achieve these goals. This type of general software could greatly reduce the cost of developing specific expert systems.

Examples of Communication and Information Management in Agriculture

While much information has been available to farmers from libraries, county extension offices and land grant universities, some innovative farmers have found the data to be lacking in overall specificity or timeliness. In the past, information often received from government agencies either did not apply to a particular geographic area, was felt to be outdated for market management decision making.

Presently USDA-FES/CES has and is establishing state networks for rapid dissemination of research results of local significance. In addition, new communications and information management systems are making it possible for farmers to access information data bases from remote locations (Chartrand, 1983).

For example, the CRIS system of USDA provides up-to-date listing of current agricultural research.

AGNET from the University of Nebraska is available in more than 40 states and contains programs for farm management, problem solving, information retrieval, and many USDA reports.

There are many experimental systems that deal with electronic trading of cattle and hogs, problem solving programs for farm management and information on pest control. Some examples of these systems are shown in Table 1.

However, by far the largest problem facing farmers using computers today is the interface between external services, such as CRIS and AGNET, and specific micro-applications (on farm applications). Systems that provide only basic information are useless to farmers without specific applications programming. There are several instances where farmers have developed their own applications oriented programs; however, these are the exceptions rather than the rule (Dresslis, 1982 and Cox, 1983).

Technological Breakthroughs Needed

Much of the technology required for farmers to adopt communications and information management systems already is available in many parts of the U.S. economy. A selection of external data bases available to agriculture is shown in Table 1. These data bases provide farmers with accessibility to software packages at a limited initial investment, and on a real time basis. There are a large number software packages including

TABLE 1. SELECTED EXAMPLES OF AGRICULTURAL INFORMATION SYSTEMS

System	Sponsoring Organization	Coverage	Information and Services Available
AGNET	Univ. of Nebraska	More than 40 states	Information and data retrieval, USDA reports on crops, livestock, Market trends, Farm management problem solving
AGRICOLA	USDA/NAL	Nationwide	Information retrieval, Bibliographic citation to books, journals, articles, and gov't reports in agriculture
Chase Econometrics Domestic Agriculture Service	Chase Econometrics	Nationwide, Canada and Europe	Information and data retrieval, Agricultural statistics and historical data, "Agricultural Model" econometric model for agricultural business analysis
CRIS	USDA	Nationwide	Information retrieval publicly supported agricultural and forestry research in U.S.
FACTS	Purdue University	All countries and 10 area extension offices in Indonesia	Farm management problem solving, Information retrieval: weather, market prices, emerging information bulletins

TABLE 1. (Continued)

System	Sponsoring Organization	Coverage	Information and Services Available
Iowa Beef Processors Satellite Communication Systems	Iowa Beef Processors, Inc.	Kansas	A satellite communications system linking IBP headquarters to field beepers
TELCOT	Plains Cotton Cooperative Assoc.	Texas and Oklahoma	Electronic trading of cotton
TELPLAN	Michigan State University	Agribusiness and extension agents in more than 30 states	Farm management problem solving
CATTLEX	Texas A&M University	Texas	Experimental electronic trading of cattle
HAMS	Ohio State University	Ohio and surrounding states	Experimental electronic trading for slaughter hogs

Source: Chartrand, R.T., A.B. Carr and N.R. Miller, "Getting Information to the Farm", *ASIS Bulletin*, February, 1983. pp 13-16.

those for general ledger accounts, payroll packages, cash flow analysis and budgeting.

An important breakthrough needed for increasing communications and information management systems on the farm is a method to stimulate farmers to learn and use information management techniques in their operations. Several recent studies have indicated that a very small proportion (3-5 percent of sample) of the farmers use microcomputers in their operations (Arthur Anderson and Company, 1982, and Bultens, 1983). Approximately 7 to 15 percent of the respondents in these studies indicated they intended to purchase a computer, while about 25 to 28 percent indicated they had given "some thought" as to how a microcomputer could be used in their operations. In both studies,the largest group of farmers, varying from 46 to 57 percent, indicated "they had not given serious thought" as to how microcomputers could be used in their operations.

In most cases the individual who is using a microcomputer and taking advantage of the information management techniques in agriculture is regarded as "an innovator" (Arthur Anderson, 1982). "Innovators" most often farm over 1,000 acres and have a college education. Conversely, those farmers who had not considered using the microcomputer in their operations operated farms averaging less than 400 acres, were older (approximately 50 years), and only a small faction had completed college (less than 10 percent).

Probably the easiest way for a farmer to understand the computer is to view the machine as a piece of farm equipment similar to a tractor or combine. A computer is a piece of machinery that permits the farmer to collect information, analyze data, and provides access to information that normally would not be part of his knowledge base.

Presently many farmers lack the technical programming experience and expertise needed to develop the software for integrating the components of an information management system for on-farm use. Much of the software now available to farmers is software that can be used in small businesses. However, there are programs for analyzing specific farm management problems, such as feeder calf purchase/sale decisions, swine management programs, and other livestock programs, but the output of those farm management programs has not been integrated into a total management information system. If greater use of computer and information management techniques is going to occur in agriculture, more software needs to be designed for farm problems with particular emphasis on a totally integrated system. This programming void could be filled by either the private sector or colleges, universities and extension services serving agriculture.

Timing to Commercialization

Before communications and information management systems will become widely accepted in U.S. agriculture, farmers need to be educated about the benefits of using integrated management information systems. Farmers need to be shown how these systems can increase farm efficiency and improve overall resource allocation. The education process will require a number of years to penetrate the present farm environment.

As farmers use computers in their daily operations data transmission needs improvement. Presently rural telephone lines are used for data transmission and the costs incurred by the farmer to use these present day systems could become prohibitive if used regularly. However, steps are being taken to improve the costs of serving rural areas using high speed lines.

Another factor is the market penetration of hardware to the farm. Some studies have predicted a five fold increase in computer use by farmers by 1987. One study predicted that 50,000 farmers will own computers, within this time period, and most will be using those computers for financial analysis, maintaining crop and livestock production records and forward planning (Arthur Anderson, 1982). As computer sales distribution networks develop in rural areas and help increase the awareness of farmers about the potential applications of computers to solving farm problems, computer equipment will diffuse rapidly into agriculture. Widespread use of the agricultural computer applications will occur before the early 1990's.

Institutional Arrangements

Much of the agricultural software developed to date has been either by land grant institutions or by innovative farmers. However, organizations traditionally dealing with the farmer are developing joint ventures with computer hardware organizations. For example, the linkage of Valmont, Inc. (a manufacturer of irrigation equipment/systems) and IBM provided IBM the first real step into the agricultural market. Valmont, using it's extensive dealer network, provided considerable exposure of the IBM computer to the agricultural market. IBM now is using a network of eight dealers to market its computer to farmers.

Until recently the most often purchased computer hardware for farm use was Radio Shack, Apple, and Texas Instruments. To a great extent software compatible with a number of various computer brands is not available.

Farmland Industries and Texas Instruments formed a linkage to introduce microcomputers through the Farmland Cooperatives. That venture was shattered when Texas Instruments withdrew from the computer market. DICKEY-john Corporation is marketing both hardware and software to agricultural users (Mauzey, 1983). DICKEY-john uses the seminar approach to teach farmers how to use computers, and presently has tied itself to Xerox microcomputer capabilities. Linkages like those just described that will provide rapid access of the computers to agriculture.

Major Impacts

One of the major impacts of farmers using communications and information technologies will increased amounts of information available for decisionmaking. Already farmers are using the computer for financial analysis, accounting, and the maintenance of crop and livestock production records. Integrating data from the farm (microdata) with the capabilities of on-line information data bases (macrodata) will enable farmers to perform numerous analyses regarding production decisions, livestock feeding decisions and farm management decisions.

The ability to integrate the microdata with the macrodata available in on-line databases will enable farmers to plan more effectively for increased revenues and greater profits. Several studies indicate that within five years innovative farmers using the computer will be maintaining production records, using the computer for business planning, monitoring receipts and expenditures, and obtaining market information (Arthur Anderson, 1982). However, the computer offers several other opportunities for farmers. Information management and communications networks have opened up a wealth of resources to the farmer, including research notes from universities, competitive product analyses, specialized crop reports, livestock marketing data, field/crop production records, livestock management and financial record keeping and planning.

For example, Figure 1 illustrates a conceptual approach for an integrated farm management information system. A number of individual data gathering and analysis operations take place in their own microenvironment, such as field or crop monitoring, livestock environment monitoring and controlling, computer controlled feeding systems, and others. Each microenvironment is controlled by its own microprocessor and routine decisions are acted upon

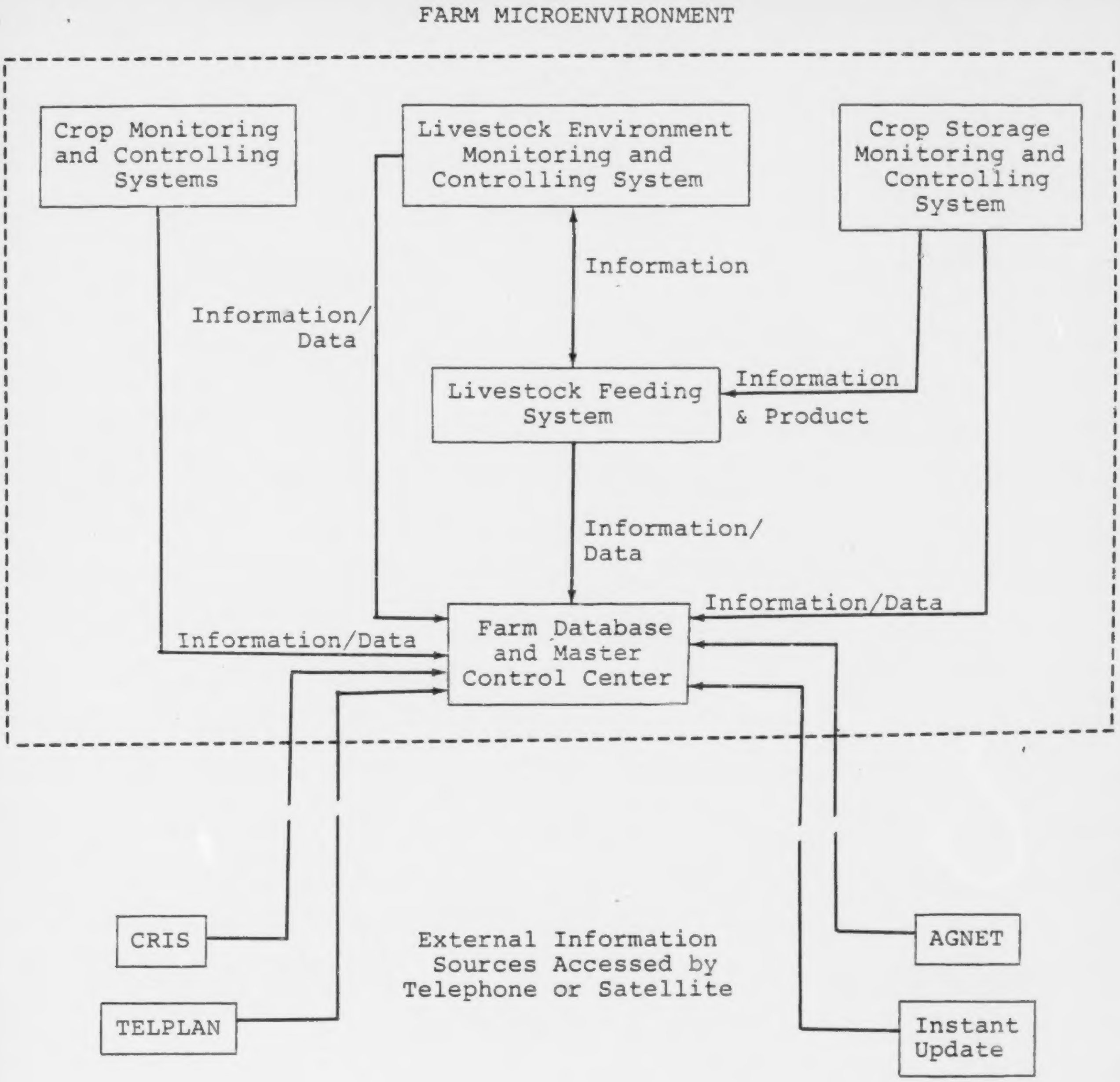

FARM MICROENVIRONMENT
Crop Monitoring and Controlling Systems
Livestock Environment Monitoring and Controlling System
Crop Storage Monitoring and Controlling System
Information
Information/ Data
Livestock Feeding System
Information & Product
Information/ Data
Information/Data
Farm Database and Master Control Center
Information/Data
CRIS
TELPLAN
External Information Sources Accessed by Telephone or Satellite
AGNET
Instant Update

FIGURE 1. DIAGRAM OF CONCEPTUAL INTEGRATED FARM MANAGEMENT INFORMATION SYSTEM

by the appropriate algorithm.[2] Information and data are transmitted to a central computer for storage and form the farm database. The integration of macrodata from external databases would enable the farmer to incorporate market information, decision making programs and data analysis programs with the farm database.[3] Effective use of an integrated farm management information system, such as the one just described, enables the farmer to become a sophisticated decisionmaker.

A second impact will be the increased demand by farmers for workshops, seminars and courses dealing with the use of computers, information management, problem solving techniques and programs and on-line computing techniques. Traditionally these services have been provided by both the land grant universities or the county extension services. For farmers to have greater exposure to information management systems, these activities will have to be scheduled more frequently, preferably during the winter months when farmers tend to have more time available to attend instructional seminars.

Several universities have made significant steps in increasing farmer's knowledge of information systems. Purdue University each fall offers an on-farm computer use conference that features an instructional format, as well as seminars provided by users experienced in problems related to farmers and farm management. Several other universities providing information on computer use and services are the University of Nebraska and Michigan State University.

---

[2] These techniques were discussed in the paper on monitoring and controlling technologies.

[3] External data bases were discussed earlier in the paper.

The use of information services by farmers will increase. As farmers become more familiar with computer operations and the importance of computer services, innovative firms will develop new services. Market services, product and livestock information services, for example, will provide farmers with greater access to timely market information that may become key information inputs to decision-making. As these services become more available farmers need to integrate them into the total information management package.

Farmers will need to devote a great deal of time to develop an understanding and experience in using communications and information management systems. For farmers that already have computers, the investments needed are not so much in hardware as in the time to understand the problems and use of the computer equipment. Many farmers are not willing to take the time required to re-educate themselves regarding these new techniques. For those farmers willing to invest in self education or continuing education, the rewards will be increased profits, efficient resource use and effective management of their agricultural endeavors.

References for Communications and Information Management

Arthur Anderson and Company, "The Management Difference: Future Information Needs of Commercial Farmers and Ranchers", Chicago, IL, 1982.

Battelle Columbus Division, selected uses of various proprietary draft papers and discussion notes.

Brook, R., and Peterson, G., "Computers on the Farm--Software Selection", Michigan State University Cooperative Extension Service Bulletin, E 1638, Dec., 1982.

Bultena, G. and Hoiberg, E., "Farmers Adapting Computers Bit by Bit", Agri Marketing, 21(2):28-31, Feb., 1983.

Chartrand, R.T., Carr, A.B., and Miller, N.R., "Getting Information to the Farm", ASIS Bulletin, pp 10-16, Feb., 1983.

Cox, M., "Farmers Growing Demand for Computers Draw Many High Tech Firms Into Market", Wall Street Journal, Dec. 22, 1983.

Diesslin, H.G., "The Computer: Management Power for Modern Agriculture", Proceedings of On-Farm Computer Use, Purdue University, Lafyette, IN, Nov. 22-23, 1982.

Hyatt, G., Jr., "Transferring Technology", Agriculture in the Twenty-First Century, J.W. Rosenblum ed., (New York: J. Wiley and Sons, 1983) pp 248-254.

Mauzey, M.L., "Reaching Your Market Through Computers", Agri Marketing, 21(2):16-20, Feb., 1983.

Nesbitt, S.R., "How Clark is Helping Dealers Use Computers", Implement and Tractor, Dec., 1983, p 26.

Rouse, R.A., "Take Command of Your Computer Conversion", Agri Marketing, 21(4):126-129, April, 1983.

Schmidt, J.R., "On Farm Information Systems", Agriculture in the Twenty-First Century, J.W. Rosenblum ed., (New York: J. Wiley and Sons, 1983) pp 214-219.

Stober, M.A., "Data Bases Bring Ag Information Home", Agri Marketing, 21(3):28-40, March, 1983.

Thompson, T.L., "Interactive Computer-Based Information Systems", Agriculture in the Twenty-First Century, ed. J.W. Rosenblum ed., New York (J. Wiley and Son, 1983) pp 220-225.

Trevis, J., "Personal Computers Seen Affecting Feed Industry", Feedstuffs, 55:(50):1, Dec. 6, 1983.

Background Paper No. 23

Monitoring and Control--Animal Agriculture

Battelle Columbus Laboratories
Columbus, Ohio

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

TABLE OF CONTENTS

Page

INTRODUCTION 1

CURRENT STATE-OF-THE-ART 1

Sensors 4

Controllers 8

Displays 11

Actuators. 11

STATE OF THE ART EXAMPLES FOR ANIMALS 13

MAJOR BREAKTHROUGHS NEEDED. 13

Timing to Commercialization. 18

INSTITUTIONAL ARRANGEMENTS. 19

POTENTIAL PRIMARY IMPACTS 21

REFERENCES 23

LIST OF TABLES

Table 1. Monitoring and Controlling Applications Used in Animal Agriculture 14

LIST OF FIGURES

Figure 1. Open Loop Control System. 2

Figure 2. Closed Loop Control System 3

Figure 3. Sensor Technologies 7

SUMMARY FOR MONITORING AND CONTROLLING TECHNOLOGIES - Animal Agriculture

Monitoring and controlling systems may be either open-loop, closed loop systems or a combination of the two. An open loop system is one in which the controllilng action is independent of the output monitored. In a closed loop system the controlling action is a function of the output monitored. A human operator "in the loop" and the control in a closed loop system, or an automatic controller makes decisions about how best to direct the actuators to optimize the system. Thus, any monitoring and controlling system can be divided into its component parts, sensors, controllers, displays, and actuators.

Sensors are devices that convert physical variables into usable outputs. Recent developments in monitoring and controlling techniques have focused on using microcomputers and controllers. Important sensor technologies include solid state electronics, optical capabilities, especially fiber optics, electro-optical low light sensors for TV displays and accoustical applications for ultrasonics.

Controllers receive inputs from sensors, decide the action to be take and direct the actuator to perform the action. To accomplish the task controllers require both hardware and software. Controllers are moving toward programmability and a high degree of computational power. The increased computational power of micro-electronics allows controllers to optimize, on a real time basis, and includes diagnostic capabilities. Software for controllers is becoming user friendly and incorporating many of the attributes of database management programs and information analysis.

A display transforms information received from a controller into a usable form for the operator. The most common display form is digital readout. The availability of displays for agricultural user is not in question.

Actuators take signals from the controller and produce a movement or force that adjusts the process which is being controlled. Current development work on actuators is focused upon smaller actuators with adequate force levels, faster operating actuators, and actuators that interface easily with digital electronics.

Monitoring and controllilng systems for animals appear to be non-fully integrated. The sensors application focuses upon control of environment, feeding rations and animal health. Most rapid advances have occurred in dairy operations where feeding ration requirements are geared to milk production and herd health, and actuators dispense prescribed rations for individual animals.

To increase the use of sensor technology in monitoring and controls for animals will require scientists to address the issue of sensor cost reduction. New fiber optic and semi-conductor sensor technologies offer hope for cost reduction breakthroughs; however, more research on the applications of these technologies is needed before cost reductions can be realized.

Another important factor is the need to develop applicable software and adapt that software to on-farm operations. The software and algorithms to automate animal agricultural operations has evolved on the piecemeal basis. Each subsystem has been designed separately and often is not compatible with other subsystems. Now subsystems are being designed using state-of-the-art technology and are being integrated as one unit.

Lower prices will create continued pressure to reduce the cost of producing agricultural outputs. One impact of adopting monitoring and controlling technologies to animal agriculture will be to improve production efficiency, increase output and effect the necessary reduction in production costs, as, for example, has happened in the dairy industry where high price supports have encouraged investments in technology, resulting in more efficient production and reduced production costs.

Another impact will be to provide farmers with greater amounts of time to manage and make critical financial decisions. As information data networks are developed for specific segments of animal agriculture, the potential impacts on increased output will increase as innovative farmers utilize the external databases to better manage internal operations.

MONITORING AND CONTROLLING TECHNOLOGIES
(Plant Agriculture)

Introduction

Monitoring and controlling systems may be either open-loop, closed loop systems or a combination of the two. An open-loop system is one in which the controlling action is independent of the output monitored (Figure 1). In a closed-loop system the controlling action is a function of the output monitored. A human operator can be "in the loop", and the control in a closed-loop system, or the control can be derived from an automatic controller. In a closed-loop system the operator or automatic controller makes decisions concerning the best way to direct the actuators to optimize the process (Figure 2). Any closed-loop monitoring and control system can be divided into its component parts; sensors, controller, display, and actuators. The following sections of this paper will look at the state-of-the-art trends of each component part and the barriers to use in agriculture, with emphasis upon closed-loop control systems.

Current State-of-the-Art

Monitoring and controlling systems have been used in agriculture for many years. For example, the simplest monitoring and controlling system has been used for centuries, by farmers, where the farmer would feel a handful of soil to determine moisture content and the need for irrigation.

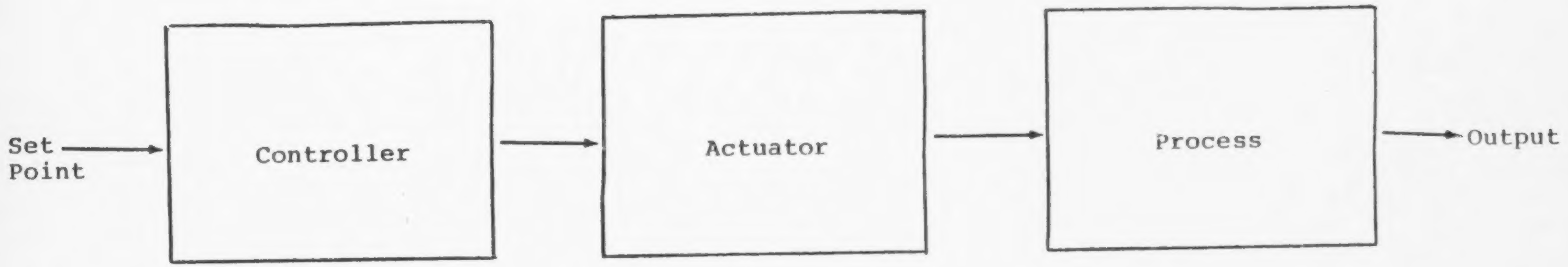

Set
Point
Controller
Actuator
Process
Output

FIGURE 1. OPEN LOOP CONTROL SYSTEM

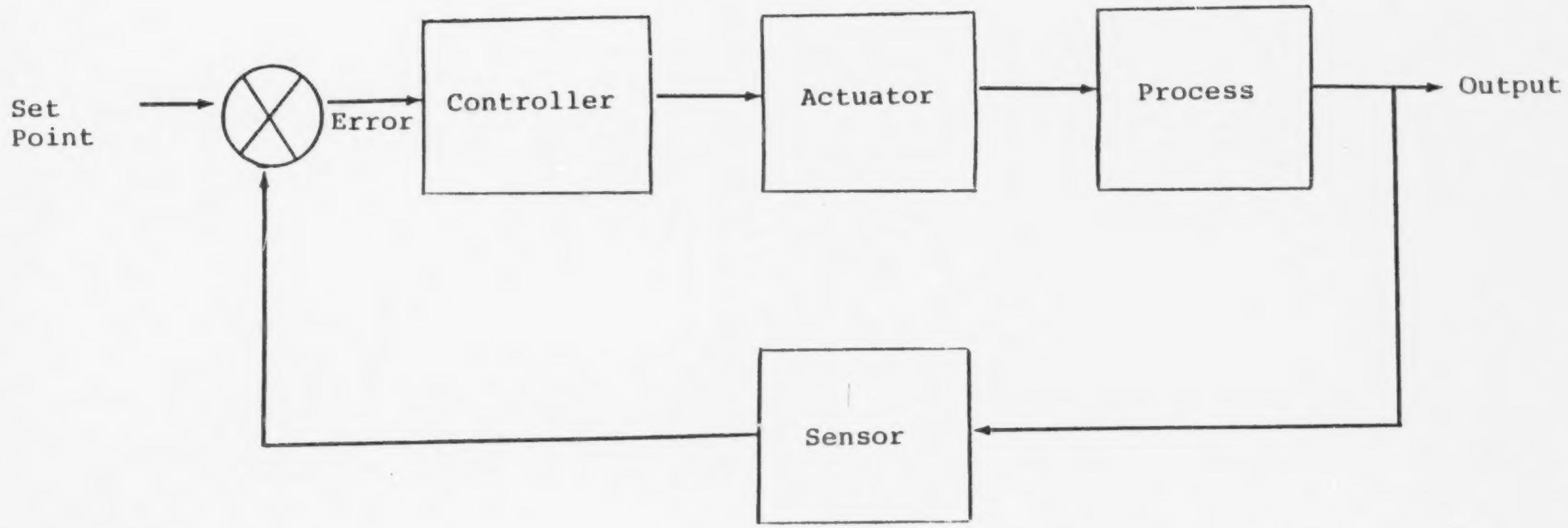

Set Point
Error
Controller
Actuator
Process
Output
Sensor

FIGURE 2. CLOSED LOOP CONTROL SYSTEM

Now sensors can be used to determine the soil moisture at various locations within the field and to control the subsequent amount of irrigated water applied to the drier areas (Hirsch, 1983). Sensors may be used to detect the number of seeds being planted and to assist in computing the expected plant population. Some controllers have been developed that use operator input to vary planter planting rates on a real time basis. Major hurdles to overcome before monitoring and controlling technologies can be widely applied to agriculture include the development and manufacture of economical and rugged sensors and the acquisition of sufficient data on which to base control programs.

Sensors

Sensors are devices which convert physical variables into usable outputs. Agriculture is concerned with sensors that can convert physical, biological or chemical phenomena into electrical outputs. Sensors can be divided into two major types. The first senses a primary parameter, such as a mercury thermometer, which measures temperature. The second senses a secondary parameter which has a relationship to the primary parameter that one wishes to measure. For example, by measuring the dielectric constant of a soybean, the moisture content of the seed can be inferred (Baskin, 1981). Sensor development trends are emphasizing secondary parameter measurements because the electrical signals produced by the sensors are more compatible with the electronic system controllers.

Therefore development trends in sensor research are greatly influenced by the advances and needs in electronics controller technology.

Recent developments in monitoring and controlling techniques have focused on using microcomputers as controllers. Microcomputer technology has advanced greatly during the past few years. The most notable items being developed include:

- Greatly reduced component prices--microprocessors now are on the order of a few dollars rather than hundreds of dollars per item
- Miniature devices--about 800,000+ gates per square inch
- Reproducible electronic output
- Mass production capability
- Incorporation of digital technology.

Changing Sensor Technology Resulting From Computer Advances. In parallel with the advances in microcomputers, the technology of sensors has been changing rapidly. Recent developments in sensing phenomena include:

- Solid state electronics--semiconductor sensors and sensors employing thick and thin film technology
- Optical capabilities, especially fiber optics,
- Electro-optical-low light sensors for display TVs, etc.
- Acoustic applications, especially ultrasonics.

The capability of sensors to measure varying and different physical data becomes more expansive as new technologies become available (Figure 3). Some sensors are including electronic processing and/or storage circuitry as a part of the sensor package. These devices are known as smart sensors. By using microelectronic manufacturing and packaging techniques, it is possible to put the sensor, amplifier, and signal processor on a single low-cost, low-power use chip. In some simple applications these sensors can act as controllers. Even in applications where the smart sensor can not act as the controller, the sensor can make the controller's function easier by performing part of the controlling function computations.

Other trends are to develop non-contact sensors, use silicon semiconductors as the sensing element, and incorporate fiber optics into sensors. Non-contact sensors can use light, microwave, ultrasonics, or other techniques to establish the presence of an object, its shape, and other characteristics (Battelle, 1984).

Using semiconductors as the sensing element often permits the miniaturization of the sensor. A sensor may be integrated with the signal processor, by using some of the techniques developed in mass production of micro-chips (Angell, 1983). Changes in force or temperature, may vary electrical characteristics of a semiconductor which can be translated into an electrical signal. Very small (about 1 mm square) inexpensive sensors may be produced using semiconductor manufacturing techniques.

Fiber optic sensors may depend upon changes in the optical properties of the fiber when it is flexed, subjected

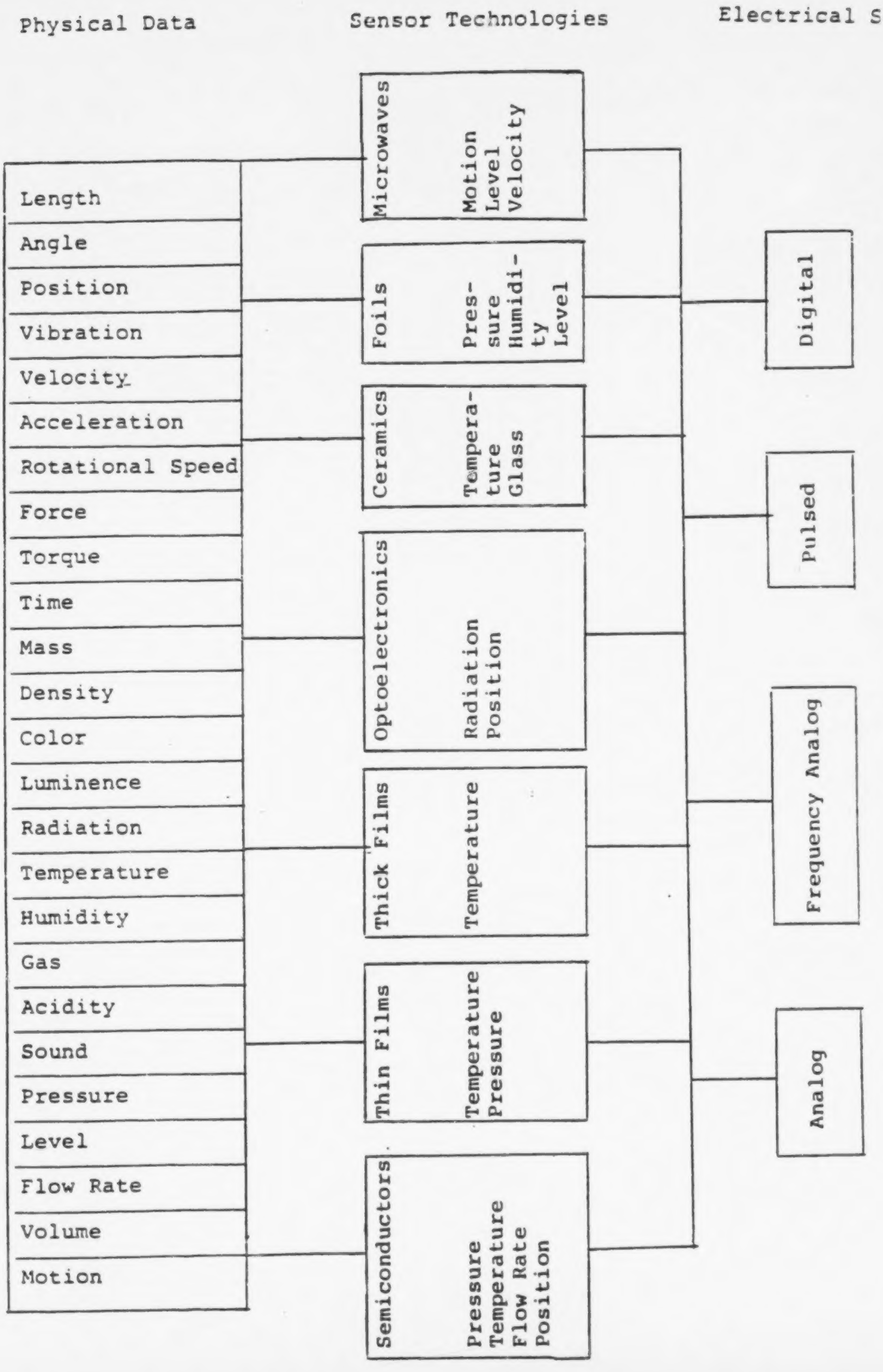

Physical Data
Sensor Technologies
Electrical Signal
Length
Angle
Position
Vibration
Velocity
Acceleration
Rotational Speed
Force
Torque
Time
Mass
Density
Color
Luminence
Radiation
Temperature
Humidity
Gas
Acidity
Sound
Pressure
Level
Flow Rate
Volume
Motion
Microwaves
Motion
Level
Velocity
Foils
Pres-
sure
Humidi-
ty
Level
Ceramics
Tempera-
ture
Glass
Optoelectronics
Radiation
Position
Thick Films
Temperature
Thin Films
Temperature
Pressure
Semiconductors
Pressure
Temperature
Flow Rate
Position
Digital
Pulsed
Frequency Analog
Analog

FIGURE 3. SELECTED SENSOR PHYSICAL MEASURMENT CAPABILITIES RELATED TO BASIC TECHNOLOGIES, AND ELECTRICAL OUTPUT SIGNAL

to a magnetic field, or when the fiber surface absorbs a certain chemical (Kingsley, 1983). Optical fibers may be used with semiconductor lasers to build a sensor relatively free from electrical interference.

Controllers

A controller is a device which receives inputs from the sensors, "decides" what action needs to be taken, and directs the actuators to perform that action. To accomplish this task requires both hardware and software. Today the hardware is readily available as programmable controllers used in industry and personal (or business) microcomputers. Adapting that hardware to mobile field machinery or for use with agricultural livestock may create temporary obstacles. For example, converting the power source from 120 volts to 12 volts DC is no simple matter, because of the severe noise and transient conditions that are present on vehicle power systems. Also, environmental stresses from chemicals, dust, shock, vibration, temperature and humidity are important factors to be considered when converting to less costly controllers for agricultural applications.

Controller software is readily available for industrial and business applications such as manufacturing resource planning (MRP), inventory control, and bar codes. Some of this software could be used in agribusiness; however, the software needed for specific monitoring and controlling of agricultural related activities presently is not widely available because:

- Today agriculture is a small market for controller software
- Development costs for controller software is expensive relative to the market size and farmers often do not have the expertise (or inclination) to program controllers
- Data acquisition capabilities and the subsequent data basis required for controllers are not widely available.

The state-of-the-art in controllers is moving toward programmability and a high degree of computational power. Lower cost, higher computational power available from microprocessor development permits the addition of logic and reprogrammability to controllers rather than dedicating the controllers to a single process through the use of hard-wired control. Controllers that can be reprogrammed, or can adjust themselves, for different uses or to handle changes in the input variables, such as summer vs. winter, are common in industrial controls. These controllers are available for use in agricultural situations today.

The future of controllers can be projected from the recent past. Controllers will become less expensive and more capable in functional performance. Computational power is expected to increase steadily over the next decade. Costs per unit of memory or per unit of computation will decline. More use will be made of custom chips, programmable read only memories (PROM), to customize generic controllers for a specific application. Presently at least one manufacturer of industrial controllers is offering a service to program a PROM to suit the industrial purchaser needs. Controllers will become more rugged so that they can operate in more hostile environments than today's machines and factories.

The increased computational power of microelectronics allows controllers to have several new uses:

- Real time optimization of processes--changing the irrigation to account for an unexpected shower,
- Equipment diagnosis-built in test (BIT),
- Real time image processing
- Adaptive control--changing the program based on trends in input data

Presently software is becoming more user friendly. These user friendly programs permit a non-computer programmer to write programs that will enable him to achieve particular goals. Probably the best examples of user friendly programs can be found in business. Spreadsheet programs, such as VISICALC and SUPERCALC 2, permit a non-computer oriented operator to prepare a computerized budget or forecast. Database management programs, such as dBASE II and Lotus 1-2-3, permit the storage and correlation of large amounts of information without the need to hire a computer programmer. These trends will continue, thereby enabling greater use of control systems.

Displays

A display is a device which transforms information received from a controller, a signal processor or a smart sensor into a form useful for the operator. Today, the most common form of display consists of dedicated displays, such as digital readouts. The trend for the future, however, is toward more flexible displays built around pictorial technologies such as CRTs, LEDs or LCDs. Current work in military applications may result in displays that will be more rugged and easier to read than presently available displays. The current availability of some display techniques for agriculture is not in question.

Actuators

Actuators take signals from the controller and produce a movement or force that adjusts the process being controlled. Typical examples of actuators include electrical, hydraulic, and pneumatic motors, hydraulic or pneumatic cylinders, and electrical solenoids and relays. These devices can vary the flow of water, open a feeding bin door, or adjust the depth of a plow.

The major focus of current development work on actuators is toward four areas:

- Energy efficient actuators
- Smaller actuators with adequate force levels

- Faster operating actuators
- Actuators that interface easily with digital electronics.

Of these four areas, only the third and fourth areas are expected to have a substantial impact on agricultural actuator use. Easing the digital electronics interface should result in reducing overall system costs and increasing system reliability.

State-of-the-Art Examples for Plant Agriculture

Many monitoring and controlling systems for plants relate to storage management (Bunn, 1983, Ksiazek, 1983, and Persson, 1983) or water management (Hirsch, 1983). Other work has revolved around process controls for fertilizers (Moerdyke, 1983) or pesticides for orchards (McConnell, 1983).

One integrated system for monitoring and controlling moisture in grain, (Persson, 1983) used a Motorola 6800 Series microprocessor in a controller that took continuous readings from temperature and relative humidity sensors. Designed to operate year round, the system combined the qualities of natural air or low heat drying of grain, and achieved continuous in-bin monitoring of the grain. Grain quality was improved while greatly reducing total energy requirements (Table 1).

There have been other reports of using microprocessor based data systems for data monitoring and controlling. Some systems are capable of integrating multiple data inputs and selecting the optimum control levels. Others are used as data loggers and controllers (Van Straalen, 1973).

Ksiazek and Funk discuss a future grain storage management system that could use current technology to manage the storage and sale of grain stored on the farm. The system would use drying and aeration control linked to a temperature monitor within the storage bin. The controller would utilize local weather information in addition to on site bin temperature monitoring.

TABLE 1. SELECTED EXAMPLES OF MONITORING AND CONTROLLING APPLICATIONS USED IN PLANT AGRICULTURE

Application	Sensor	Controller	Actuator	Software
1. Microprocessor Systems for Soil and Well Monitoring (Hirsch, 1983)	Soil sensors linked by radio to controller, buried at various depths	Microprocessors	Magnetic relays to turn pump motors on and off	Provided farmers with data on moisture, selected optimal irrigation strategy, Described pump performance and maintenance and overhaul schedule
2. Measurement of Tree Volume for Spraying (McConnell, 1983)	Polaroid pulse-echo ultrasonic ranging transducers	Apple Microcomputer		Calculate volume of target tree to estimate amount of spray material required for disease control
3. Grain Drying and Aeration (Persson, 1983)	Temperature Semiconductor Type LM335 Relative Humidity Gold plated dielectric capacitor	Motorola 6800 microprocessor	Manual and automatic	Monitored grain condition during storage for periodic aeration to control drying costs and grain quality
4. Sugarbeet Storage and Control (Van Straalen, 1983)	Temperature Copper/constantas thermocouples Humidity Weathertronics Model 5131(2) Weight Load cells	Hewlett-Packard 3054 DL containing a 3497A data acquisition/control unit and HP85F controller	Computer controlled fans for storage bin humidifier	Process control, data collection, data reduction and storage, data files, data retrieving and output (graphics), maintained temperature and relative humidity within predetermined parameters, maintenance product records

Integrating the information of grain moisture with market conditions would enable the farmer to sell at the most advantageous time.

Hirsch, et. al, describes an irrigation management system that uses remote soil sensor stations that communicates with the controller by radio link. Each soil sensor station can support as many as four soil moisture sensors buried at various depths. The pumps are controlled by magnetic relays. The system provides the farmer with data describing the moisture state in the field, optimal irrigation strategy, and recommended maintenance and overhaul schedules for the pumping system.

Use of sensor technology has been progressing rapidly in agricultural machinery applications. Doppler radar, measures the true ground speed of tractors. Tractor wheel slippage affects ground speed and is a critical element in determining real application rates for fertilizers and pesticides. Seed planters use sensors for measuring seed population as well as the operation of planting functions. Color sensors used for separating ripe and upripe fruit are important elements in mechanical tomato harvesters. Sensors on combines are used to detect grain loss during harvesting. Overall, the application of sensing techniques is rather advanced in farm machinery.

Major Breakthroughs Needed

The problems associated with monitoring and controlling plant agriculture appear to be more complex than those associated with animal agriculture. Earlier examples of closed loop systems demonstrate that monitoring and controlling activities often can be accomplished at reasonable economic costs. However, before farmers integrate advanced technologies into their operations additional work needs to be done in several areas.

First, work needs to be done to determine the relevant parameters that need to be monitored. If one assumes that sensors are needed in field applications to measure moisture, nitrogen, phosphorous or even residual herbicides and provide a "read out" of the field's condition to the farmer, one needs to know the variable to be measured. Second, present sensors are not universally adaptable to measure several variables at the same time. Each must be designed for a specific variable and the parameters for that variable need to be established. Therefore, unless a universal sensor is developed (one that measures many variables) or unless unit sensor costs drop dramatically, agriculture is faced with large capital investments for sensors. Present sensors can measure liquid levels, pH, chemical concentrations, temperature and pressure to extreme degrees of accuracy. To provide direction to researchers in the sensor area, a cost/benefit study is needed to estimate the value of specific sensors.

Excluding cost considerations, there are two additional problems that need to be overcome. First, to obtain meaningful data for crop agriculture, numerous sensors need to be located throughout the field to monitor variables such as moisture, nitrogen, phosphorous, and potassium concentrations, chemical residues, etc., and will require software and algorithms to sort the information for controlling purposes. Second, if the sensors are to be mounted on farm machinery, the sensors need to be rugged enough to function properly in an adverse environment while still providing the data for controlling. For example, a corn planter may have a sensor in front of the planting shoe that measures nitrogen and moisture in the soil. An algorithm could convert the nitrogen data into fertilizer requirements and adjust the fertilizer application. The moisture data, with the appropriate algorithm, may be used to adjust the planting depth of the corn to take advantage of specific moisture and soil conditions that could enhance seed germination. If additional time series weather data could be incorporated with the planting algorithm it could increase the probability of seedling growth thereby potentially increasing yields.

Obviously, the sensors in the previous example need to be durable and rugged, able to rapidly transmit data for analysis, and capable of making real time adjustments. Presently sensors exist to perform many of these measurements. In addition, silicon micromechanical devices are available with integrated circuits and on-board capability. The high cost of these sensors presently prohibits their wide-scale use in agriculture.

Fiber optics hold substantial promise when transmitting information from remote locations on the farm. Relative to some sensors, fiber optic systems are inexpensive. For agricultural uses, however, the costs of fiber optics systems will have to decline markedly before widespread application will be feasible.

Timing to Commercialization

Some sensors for closed loop systems may not be economically available to agriculture for five to ten years. Much of the technology diffused from aerospace and military application to automotive and industrial users has not yet reached the farm in quantity. As costs decline and microprocessors become more affordable, the simplier sensors will be incorporated in agricultural systems. Present projections for the average selling price of solid state sensors are $4-$8 by the mid-1980's. Continuation of these downward price trends should make these components widely available to agriculture in the 1990's.

Fiber optic systems may not be applied to plant agriculture until the late 1990's. Economics and the need to cover remote locations will tend to retard wide-scale application of this technology. However, fiber optics has the potential for many uses in agriculture. As farmers understand the potentials of these technologoes there will be a tendency to develop it for specific applications.

Institutional Arrangements

Most of the development work on sensors has come from the private sector, particularly those firms engaged in developing military and aerospace applications. Firms such as Foxboro, Systems West division of Conrac Corporation, Motorola, Honeywell, and Texas Instruments produce and develop sensors. Most of these firms have limited contact with agriculture and therefore diffusion to agriculture may be somewhat slow. Universities also have made technological breakthroughs in sensor development. State-of-the-art advancements, however, have come and probably will continue to come from innovative firms outside of agriculture. The diffusion of technology will occur when collaboration between scientists and engineers in agricultural attack mutually attack common problems.

Potential Primary Impacts

The use of electronics for monitoring and controlling plant agriculture in the United States will have direct and indirect impacts. The primary direct impact will be enabling the farmer to be more a manager of resources and less a laborer. Time that was once spent on repetitive tasks requiring little thought will be spent analyzing data obtained from various sectors of the farm. Monitoring and controlling systems will be used to maximize the resources while minimizing production costs.

Another direct impact will be an increase production per unit of input. Since the variable inputs of production will be approaching optimal levels, output per unit of input will increase. The risk of reduced crop output because of adverse weather will be minimized; therefore, crop output should be more uniform in quality while gradually increasing in quantity.

The integration of information to efficiently operate the monitoring and controlling systems will create a number of opportunities for support services to the farmer. Foremost will be development of software to fully analyze the data obtained in the farming operations. While farmers may know the desired outcome, the means to achieve the end may not be obvious. Data management specialists, computer programmers, and others knowledgeable about data handling methods will have opportunities to influence the directions of farm management. The Extension Service land grant universities should fill training voids by conducting training sessions to educate farmers in effective methods of using monitoring and controlling techniques.

For monitoring and controlling of plant agriculture to be effective, communications and information management technologies need to be further diffused into agriculture. The lack of adequate software development to fully utilize the new technologies will be overcome as universities and private firms fill obvious voids. The capital investments required by farmers must not create barriers to widescale adoption of the technology. The greatest inhibiting factor will be the ability of the individual farmer to grasp the complete significance of using monitoring and controlling techniques for plant agriculture. Crops most likely to have these techniques applied include corn, cotton, soybeans. Horticultural crops that have high production costs may be neglected because the potential payoff of using sensors in these highly managed applications does not presently justify the development costs.

In order to collect adequate information it may be necessary for farmers to incorporate data collection devices on their farm machinery. As in the earlier example of the corn planter, the farmer could have a continous record of fertilizer and planting data that could be taken to the main computer for storage and subsequent updating and analysis of farm files.

Farmers that adopt monitoring and controlling techniques for plant agriculture will be producing higher quality crops, obtaining premium prices and engaging in more profitable farming activities. The very fact that a large production segment of agriculture is using these advanced techniques will serve to apply pressure to those less advanced segments to catch up. The tendency will be to squeeze the farmer that is not a forward thinker. The converse, however, will be to enable farm operations that are at the margin to become profitable through the efficient utilization of the available resources. The effective use of purchased inputs and the timely marketing of output will achieve the most favorable product prices and benefits for both the farmer and the consumer.

References for Monitoring and Controlling Technologies for Plants

Angell, J.B., Terry, S.C., and Barth, P.W., "Silicon Micromechanical Devices", Scientific American, pp 44-55, April, 1983.

Battelle Columbus Division, discussions with sensors experts, Jan., 1984.

Bunn, J.M., Dunlap, J.L., and Hammond, G., "Energy Efficient Drying Through Computer Control", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Firestone, L.M. and McClure, W.F., "VLSI Architectures for Image Processing", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, Il, Dec. 11-13, 1983.

Hirsch, M., Dean, S.P., Lice, B., et al, "Distributed Microprocessor Systems for Soil and Well Monitoring", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Ksiazek, T.F., and Funk, R.C., "Storage Management Using Distributed Processing", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

McConnell, R.C., Elliot, K.C., Blizzard, S.H., et al., "Electronic Measurement of Tree-Row-Volume", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Moerdyke, D.D., "The Utilization of a Programmable Controller for Process Control of a Fertilizer Blend Plant", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Persson, G.W. and Churchhill, R.W., "Automatic Computer Control of Grain Drying and Aeriation", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, December 11-13, 1983.

Warnock, W.K. and Wofler, P.D., "Microprocessor Control of a Cross-flow Grain Dryer Test Unit", Agricultural Experiment Station, University of Arkansas, Fayetteville, Arkansas.

Van Straalen, E., Kreisil, H., and Peterson, C.L., "Microcomputer Data Acquisition and Control for Sugarbeet Storage", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Background Paper No. 25

Telecommunication

Battelle Columbus Laboratories
Columbus, Ohio

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

TABLE OF CONTENTS

Page

INTRODUCTION 1

STATE-OF-THE-ART 2

    Digital Communication. 4

    Fiber Optics. 4

    Personal Computers. 5

    Videotex and Teletex 6

    Value Added Networks 8

    Integrated Services Digital Network 9

    Remote Sensing 10

    Selected Examples of Telecommunications State-of-the-Art in Agriculture. 12

MAJOR BREAKTHROUGHS NEEDED. 15

INSTITUTIONAL ARRANGEMENTS. 17

MAJOR IMPLICATIONS 18

REFERENCES 21

LIST OF TABLES

Table 1. Summary of Telecommunication Presentation Types and Transmission Medium and Rates. . 3

SUMMARY FOR TELECOMMUNICATIONS

Anticipated future developments in telecommunications are digital communications, fiber optics, personal computers, videotex and teletext, value added networks, remote sensing and Integrated Services Digital Network. The evolution of telecommunications has been driven by the different requirements of various users, such as the amount of information to be transmitted, the distribution, transmission quality and the type of information presented (voice, text, graphics).

Digital communications refers to electronic messages that are transferred in discrete elements, as opposed to a continuous wave. Digital communications uses low cost computing equipment for network control, switching and signal handling.

Fiber optics uses light rather than electricity to transmit the signal. Fiber optics requires less amplification and is not affected by electronics noise.

Personal computers are penetrating agricultural markets. Telecommunications networks for personal computers are available from firms such as CompuServe, The Source and others.

Videotex is a public two-way interactive service that provides consumers on-line access to information. The interaction mode of videotex makes it feasible to carry information and data for users.

Value Added Networks will be a major element in the future communications environment. The "added" services of these networks are protocol, code, format conversions, gateways to other networks and electronic mail services.

Integrated Services Digital Network is a digital telephone network that can simultaneously transmit digital voice, data and a variety of other services. This system enables data to be transmitted over telephone lines by audio modems.

Remote sensing is the recording and analysis of electromagnetic radiation from the earth to estimate crop yields, monitor surface water, soil erosion, climate conditions and crop or vegetation stress from insects or disease.

Many of the telecommunications technologies that will be used by agriculture during the next 5 to 10 years are already operational within the present telecommunications network. The biggest problem is the ability to provide service to rural America on a cost effective basis. A major telecommunications trend will be the use of teleport technology. Teleports will provide linkages to multiple telecommunications services (satellites) and be accessible on a regional basis.

The major implication of agriculture using telecommunications systems will be to provide farmers with a greater resources for decision making. To access remote computer services, on line data bases, videotex and teletex systems will require that farmers be better organized in how they think about their operation, how they gather information and the way the information will be used in decision making.

On line marketing services should be capable of reducing marketing costs by eliminating terminal market and other marketing charges, as well as reducing transportation costs. The system provides greater exposure and information to buyers and sellers.

For farmers to market in a timely manner has substantial revenue implications. Where videotex systems are used to link buyers and sellers, timely marketing can occur resulting in potentially higher revenues to farmers.

MONITORING AND CONTROLLING TECHNOLOGIES
(Plant Agriculture)

Introduction

Monitoring and controlling systems may be either open-loop, closed loop systems or a combination of the two. An open-loop system is one in which the controlling action is independent of the output monitored (Figure 1). In a closed-loop system the controlling action is a function of the output monitored. A human operator can be "in the loop", and the control in a closed-loop system, or the control can be derived from an automatic controller. In a closed-loop system the operator or automatic controller makes decisions concerning the best way to direct the actuators to optimize the process (Figure 2). Any closed-loop monitoring and control system can be divided into its component parts; sensors, controller, display, and actuators. The following sections of this paper will look at the state-of-the-art trends of each component part and the barriers to use in agriculture, with emphasis upon closed-loop control systems.

Current State-of-the-Art

Monitoring and controlling systems have been used in agriculture for many years. For example, the simplest monitoring and controlling system has been used for centuries, by farmers, where the farmer would feel a handful of soil to determine moisture content and the need for irrigation.

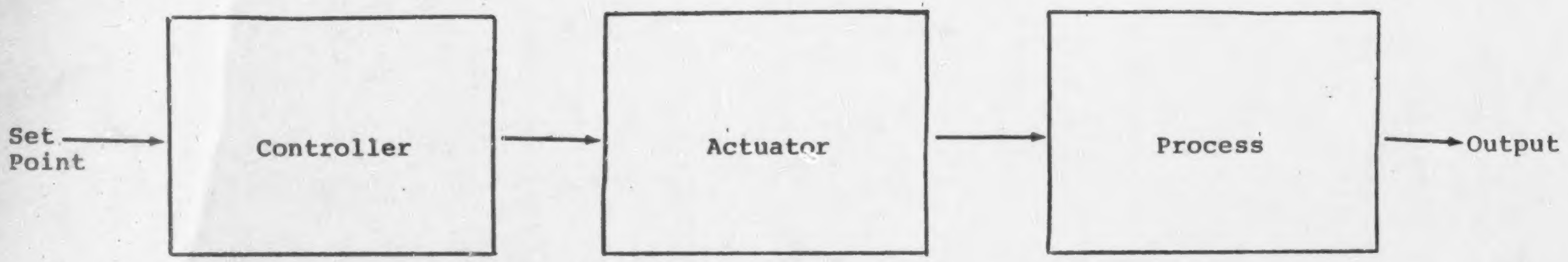

Set
Point
Controller
Actuator
Process
Output

FIGURE 1. OPEN LOOP CONTROL SYSTEM

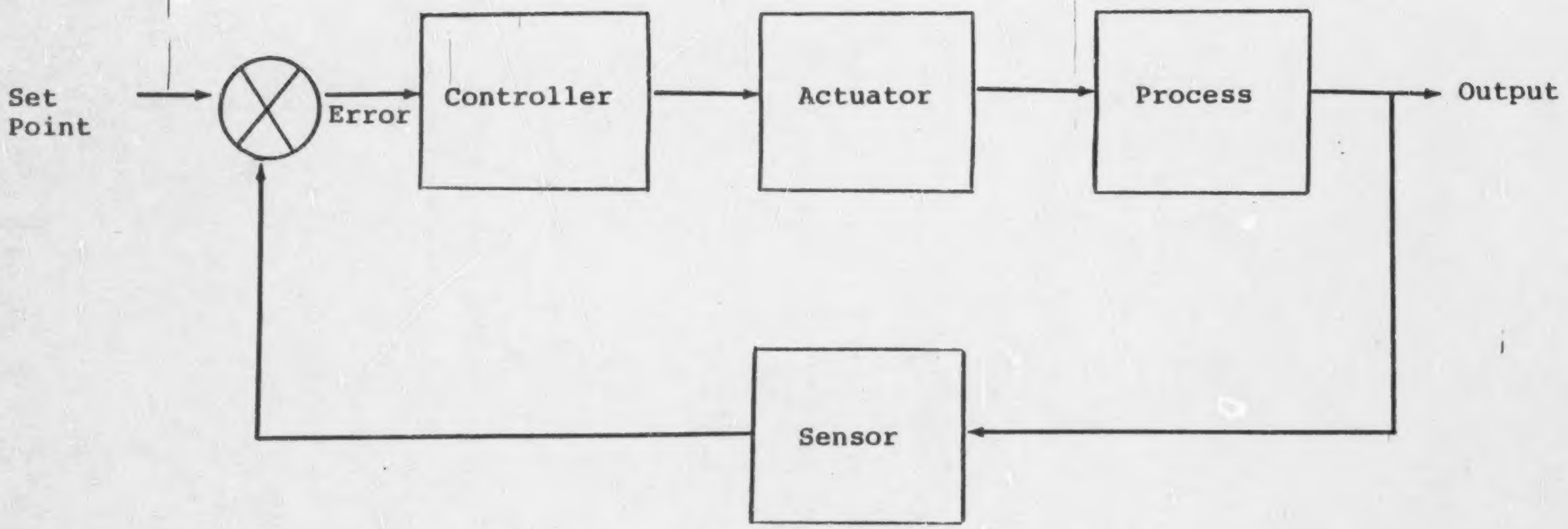

Set
Point
Error
Controller
Actuator
Process
Output
Sensor

FIGURE 2. CLOSED LOOP CONTROL SYSTEM

Now sensors can be used to determine the soil moisture at various locations within the field and to control the subsequent amount of irrigated water applied to the drier areas (Hirsch, 1983). Sensors may be used to detect the number of seeds being planted and to assist in computing the expected plant population. Some controllers have been developed that use operator input to vary planter planting rates on a real time basis. Major hurdles to overcome before monitoring and controlling technologies can be widely applied to agriculture include the development and manufacture of economical and rugged sensors and the acquisition of sufficient data on which to base control programs.

Sensors

Sensors are devices which convert physical variables into usable outputs. Agriculture is concerned with sensors that can convert physical, biological or chemical phenomena into electrical outputs. Sensors can be divided into two major types. The first senses a primary parameter, such as a mercury thermometer, which measures temperature. The second senses a secondary parameter which has a relationship to the primary parameter that one wishes to measure. For example, by measuring the dielectric constant of a soybean, the moisture content of the seed can be inferred (Baskin, 1981). Sensor development trends are emphasizing secondary parameter measurements because the electrical signals produced by the sensors are more compatible with the electronic system controllers.

Therefore development trends in sensor research are greatly influenced by the advances and needs in electronics controller technology.

Recent developments in monitoring and controlling techniques have focused on using microcomputers as controllers. Microcomputer technology has advanced greatly during the past few years. The most notable items being developed include:

- Greatly reduced component prices--microprocessors now are on the order of a few dollars rather than hundreds of dollars per item
- Miniature devices--about 800,000+ gates per square inch
- Reproducible electronic output
- Mass production capability
- Incorporation of digital technology.

Changing Sensor Technology Resulting From Computer Advances. In parallel with the advances in microcomputers, the technology of sensors has been changing rapidly. Recent developments in sensing phenomena include:

- Solid state electronics--semiconductor sensors and sensors employing thick and thin film technology
- Optical capabilities, especially fiber optics,
- Electro-optical-low light sensors for display TVs, etc.
- Acoustic applications, especially ultrasonics.

The capability of sensors to measure varying and different physical data becomes more expansive as new technologies become available (Figure 3). Some sensors are including electronic processing and/or storage circuitry as a part of the sensor package. These devices are known as smart sensors. By using microelectronic manufacturing and packaging techniques, it is possible to put the sensor, amplifier, and signal processor on a single low-cost, low-power use chip. In some simple applications these sensors can act as controllers. Even in applications where the smart sensor can not act as the controller, the sensor can make the controller's function easier by performing part of the controlling function computations.

Other trends are to develop non-contact sensors, use silicon semiconductors as the sensing element, and incorporate fiber optics into sensors. Non-contact sensors can use light, microwave, ultrasonics, or other techniques to establish the presence of an object, its shape, and other characteristics (Battelle, 1984).

Using semiconductors as the sensing element often permits the miniaturization of the sensor. A sensor may be integrated with the signal processor, by using some of the techniques developed in mass production of micro-chips (Angell, 1983). Changes in force or temperature, may vary electrical characteristics of a semiconductor which can be translated into an electrical signal. Very small (about 1 mm square) inexpensive sensors may be produced using semiconductor manufacturing techniques.

Fiber optic sensors may depend upon changes in the optical properties of the fiber when it is flexed, subjected

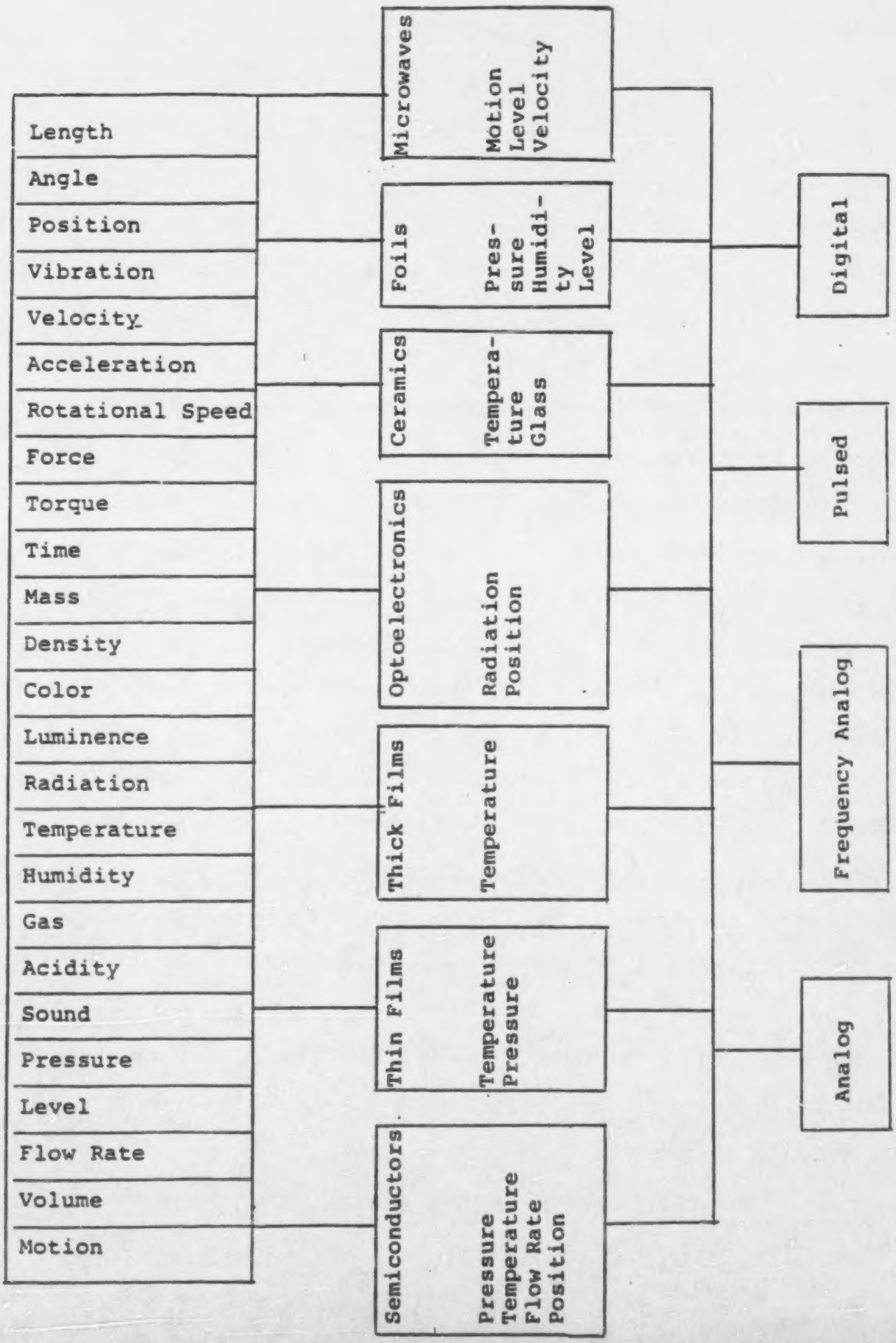

Physical Data
Sensor Technologies
Electrical Signal
Length
Angle
Position
Vibration
Velocity
Acceleration
Rotational Speed
Force
Torque
Time
Mass
Density
Color
Luminence
Radiation
Temperature
Humidity
Gas
Acidity
Sound
Pressure
Level
Flow Rate
Volume
Motion
Microwaves
Motion
Level
Velocity
Foils
Pres-
sure
Humidi-
ty
Level
Ceramics
Tempera-
ture
Glass
Optoelectronics
Radiation
Position
Thick Films
Temperature
Thin Films
Temperature
Pressure
Semiconductors
Pressure
Temperature
Flow Rate
Position
Digital
Pulsed
Frequency Analog
Analog

FIGURE 3. SELECTED SENSOR PHYSICAL MEASURMENT CAPABILITIES RELATED TO BASIC TECHNOLOGIES, AND ELECTRICAL OUTPUT SIGNAL

to a magnetic field, or when the fiber surface absorbs a certain chemical (Kingsley, 1983). Optical fibers may be used with semiconductor lasers to build a sensor relatively free from electrical interference.

Controllers

A controller is a device which receives inputs from the sensors, "decides" what action needs to be taken, and directs the actuators to perform that action. To accomplish this task requires both hardware and software. Today the hardware is readily available as programmable controllers used in industry and personal (or business) microcomputers. Adapting that hardware to mobile field machinery or for use with agricultural livestock may create temporary obstacles. For example, converting the power source from 120 volts to 12 volts DC is no simple matter, because of the severe noise and transient conditions that are present on vehicle power systems. Also, environmental stresses from chemicals, dust, shock, vibration, temperature and humidity are important factors to be considered when converting to less costly controllers for agricultural applications.

Controller software is readily available for industrial and business applications such as manufacturing resource planning (MRP), inventory control, and bar codes. Some of this software could be used in agribusiness; however, the software needed for specific monitoring and controlling of agricultural related activities presently is not widely available because:

- Today agriculture is a small market for controller software
- Development costs for controller software is expensive relative to the market size and farmers often do not have the expertise (or inclination) to program controllers
- Data acquisition capabilities and the subsequent data basis required for controllers are not widely available.

The state-of-the-art in controllers is moving toward programmability and a high degree of computational power. Lower cost, higher computational power available from microprocessor development permits the addition of logic and reprogrammability to controllers rather than dedicating the controllers to a single process through the use of hard-wired control. Controllers that can be reprogrammed, or can adjust themselves, for different uses or to handle changes in the input variables, such as summer vs. winter, are common in industrial controls. These controllers are available for use in agricultural situations today.

The future of controllers can be projected from the recent past. Controllers will become less expensive and more capable in functional performance. Computational power is expected to increase steadily over the next decade. Costs per unit of memory or per unit of computation will decline. More use will be made of custom chips, programmable read only memories (PROM), to customize generic controllers for a specific application. Presently at least one manufacturer of industrial controllers is offering a service to program a PROM to suit the industrial purchaser needs. Controllers will become more rugged so that they can operate in more hostile environments than today's machines and factories.

The increased computational power of microelectronics allows controllers to have several new uses:

- Real time optimization of processes--changing the irrigation to account for an unexpected shower,
- Equipment diagnosis-built in test (BIT),
- Real time image processing
- Adaptive control--changing the program based on trends in input data

Presently software is becoming more user friendly. These user friendly programs permit a non-computer programmer to write programs that will enable him to achieve particular goals. Probably the best examples of user friendly programs can be found in business. Spreadsheet programs, such as VISICALC and SUPERCALC 2, permit a non-computer oriented operator to prepare a computerized budget or forecast. Database management programs, such as dBASE II and Lotus 1-2-3, permit the storage and correlation of large amounts of information without the need to hire a computer programmer. These trends will continue, thereby enabling greater use of control systems.

Displays

A display is a device which transforms information received from a controller, a signal processor or a smart sensor into a form useful for the operator. Today, the most common form of display consists of dedicated displays, such as digital readouts. The trend for the future, however, is toward more flexible displays built around pictorial technologies such as CRTs, LEDs or LCDs. Current work in military applications may result in displays that will be more rugged and easier to read than presently available displays. The current availability of some display techniques for agriculture is not in question.

Actuators

Actuators take signals from the controller and produce a movement or force that adjusts the process being controlled. Typical examples of actuators include electrical, hydraulic, and pneumatic motors, hydraulic or pneumatic cylinders, and electrical solenoids and relays. These devices can vary the flow of water, open a feeding bin door, or adjust the depth of a plow.

The major focus of current development work on actuators is toward four areas:

- Energy efficient actuators
- Smaller actuators with adequate force levels

- Faster operating actuators
- Actuators that interface easily with digital electronics.

Of these four areas, only the third and fourth areas are expected to have a substantial impact on agricultural actuator use. Easing the digital electronics interface should result in reducing overall system costs and increasing system reliability.

State-of-the-Art Examples for Plant Agriculture

Many monitoring and controlling systems for plants relate to storage management (Bunn, 1983, Ksiazek, 1983, and Persson, 1983) or water management (Hirsch, 1983). Other work has revolved around process controls for fertilizers (Moerdyke, 1983) or pesticides for orchards (McConnell, 1983).

One integrated system for monitoring and controlling moisture in grain, (Persson, 1983) used a Motorola 6800 Series microprocessor in a controller that took continuous readings from temperature and relative humidity sensors. Designed to operate year round, the system combined the qualities of natural air or low heat drying of grain, and achieved continuous in-bin monitoring of the grain. Grain quality was improved while greatly reducing total energy requirements (Table 1).

There have been other reports of using microprocessor based data systems for data monitoring and controlling. Some systems are capable of integrating multiple data inputs and selecting the optimum control levels. Others are used as data loggers and controllers (Van Straalen, 1973).

Ksiazek and Funk discuss a future grain storage management system that could use current technology to manage the storage and sale of grain stored on the farm. The system would use drying and aeration control linked to a temperature monitor within the storage bin. The controller would utilize local weather information in addition to on site bin temperature monitoring.

TABLE 1. SELECTED EXAMPLES OF MONITORING AND CONTROLLING APPLICATIONS USED IN PLANT AGRICULTURE

Application	Sensor	Controller	Actuator	Software
1. Microprocessor Systems for Soil and Well Monitoring (Hirsch, 1983)	Soil sensors linked by radio to controller, buried at various depths	Microprocessors	Magnetic relays to turn pump motors on and off	Provided farmers with data on moisture, selected optimal irrigation strategy, Described pump performance and maintenance and overhaul schedule
2. Measurement of Tree Volume for Spraying (McConnell, 1983)	Polaroid pulse-echo ultrasonic ranging transducers	Apple Microcomputer		Calculate volume of target tree to estimate amount of spray material required for disease control
3. Grain Drying and Aeration (Persson, 1983)	Temperature Semiconductor Type LM335 Relative Humidity Gold plated dielectric capacitor	Motorola 6800 microprocessor	Manual and automatic	Monitored grain condition during storage for periodic aeration to control drying costs and grain quality
4. Sugarbeet Storage and Control (Van Straalen, 1983)	Temperature Copper/constantas thermocouples Humidity Weathertronics Model 5131(2) Weight Load cells	Hewlett-Packard 3054 DL containing a 3497A data acquisition/control unit and HP85F controller	Computer controlled fans for storage bin humidifier	Process control, data collection, data reduction and storage, data files, data retrieving and output (graphics), maintained temperature and relative humidity within predetermined parameters, maintenance product records

Integrating the information of grain moisture with market conditions would enable the farmer to sell at the most advantageous time.

Hirsch, et. al, describes an irrigation management system that uses remote soil sensor stations that communicates with the controller by radio link. Each soil sensor station can support as many as four soil moisture sensors buried at various depths. The pumps are controlled by magnetic relays. The system provides the farmer with data describing the moisture state in the field, optimal irrigation strategy, and recommended maintenance and overhaul schedules for the pumping system.

Use of sensor technology has been progressing rapidly in agricultural machinery applications. Doppler radar, measures the true ground speed of tractors. Tractor wheel slippage affects ground speed and is a critical element in determining real application rates for fertilizers and pesticides. Seed planters use sensors for measuring seed population as well as the operation of planting functions. Color sensors used for separating ripe and upripe fruit are important elements in mechanical tomato harvesters. Sensors on combines are used to detect grain loss during harvesting. Overall, the application of sensing techniques is rather advanced in farm machinery.

Major Breakthroughs Needed

The problems associated with monitoring and controlling plant agriculture appear to be more complex than those associated with animal agriculture. Earlier examples of closed loop systems demonstrate that monitoring and controlling activities often can be accomplished at reasonable economic costs. However, before farmers integrate advanced technologies into their operations additional work needs to be done in several areas.

First, work needs to be done to determine the relevant parameters that need to be monitored. If one assumes that sensors are needed in field applications to measure moisture, nitrogen, phosphorous or even residual herbicides and provide a "read out" of the field's condition to the farmer, one needs to know the variable to be measured. Second, present sensors are not universally adaptable to measure several variables at the same time. Each must be designed for a specific variable and the parameters for that variable need to be established. Therefore, unless a universal sensor is developed (one that measures many variables) or unless unit sensor costs drop dramatically, agriculture is faced with large capital investments for sensors. Present sensors can measure liquid levels, pH, chemical concentrations, temperature and pressure to extreme degrees of accuracy. To provide direction to researchers in the sensor area, a cost/benefit study is needed to estimate the value of specific sensors.

Excluding cost considerations, there are two additional problems that need to be overcome. First, to obtain meaningful data for crop agriculture, numerous sensors need to be located throughout the field to monitor variables such as moisture, nitrogen, phosphorous, and potassium concentrations, chemical residues, etc., and will require software and algorithms to sort the information for controlling purposes. Second, if the sensors are to be mounted on farm machinery, the sensors need to be rugged enough to function properly in an adverse environment while still providing the data for controlling. For example, a corn planter may have a sensor in front of the planting shoe that measures nitrogen and moisture in the soil. An algorithm could convert the nitrogen data into fertilizer requirements and adjust the fertilizer application. The moisture data, with the appropriate algorithm, may be used to adjust the planting depth of the corn to take advantage of specific moisture and soil conditions that could enhance seed germination. If additional time series weather data could be incorporated with the planting algorithm it could increase the probability of seedling growth thereby potentially increasing yields.

Obviously, the sensors in the previous example need to be durable and rugged, able to rapidly transmit data for analysis, and capable of making real time adjustments. Presently sensors exist to perform many of these measurements. In addition, silicon micromechanical devices are available with integrated circuits and on-board capability. The high cost of these sensors presently prohibits their wide-scale use in agriculture.

Fiber optics hold substantial promise when transmitting information from remote locations on the farm. Relative to some sensors, fiber optic systems are inexpensive. For agricultural uses, however, the costs of fiber optics systems will have to decline markedly before widespread application will be feasible.

Timing to Commercialization

Some sensors for closed loop systems may not be economically available to agriculture for five to ten years. Much of the technology diffused from aerospace and military application to automotive and industrial users has not yet reached the farm in quantity. As costs decline and microprocessors become more affordable, the simplier sensors will be incorporated in agricultural systems. Present projections for the average selling price of solid state sensors are $4-$8 by the mid-1980's. Continuation of these downward price trends should make these components widely available to agriculture in the 1990's.

Fiber optic systems may not be applied to plant agriculture until the late 1990's. Economics and the need to cover remote locations will tend to retard wide-scale application of this technology. However, fiber optics has the potential for many uses in agriculture. As farmers understand the potentials of these technologoes there will be a tendency to develop it for specific applications.

Institutional Arrangements

Most of the development work on sensors has come from the private sector, particularly those firms engaged in developing military and aerospace applications. Firms such as Foxboro, Systems West division of Conrac Corporation, Motorola, Honeywell, and Texas Instruments produce and develop sensors. Most of these firms have limited contact with agriculture and therefore diffusion to agriculture may be somewhat slow. Universities also have made technological breakthroughs in sensor development. State-of-the-art advancements, however, have come and probably will continue to come from innovative firms outside of agriculture. The diffusion of technology will occur when collaboration between scientists and engineers in agricultural attack mutually attack common problems.

Potential Primary Impacts

The use of electronics for monitoring and controlling plant agriculture in the United States will have direct and indirect impacts. The primary direct impact will be enabling the farmer to be more a manager of resources and less a laborer. Time that was once spent on repetitive tasks requiring little thought will be spent analyzing data obtained from various sectors of the farm. Monitoring and controlling systems will be used to maximize the resources while minimizing production costs.

Another direct impact will be an increase production per unit of input. Since the variable inputs of production will be approaching optimal levels, output per unit of input will increase. The risk of reduced crop output because of adverse weather will be minimized; therefore, crop output should be more uniform in quality while gradually increasing in quantity.

The integration of information to efficiently operate the monitoring and controlling systems will create a number of opportunities for support services to the farmer. Foremost will be development of software to fully analyze the data obtained in the farming operations. While farmers may know the desired outcome, the means to achieve the end may not be obvious. Data management specialists, computer programmers, and others knowledgeable about data handling methods will have opportunities to influence the directions of farm management. The Extension Service land grant universities should fill training voids by conducting training sessions to educate farmers in effective methods of using monitoring and controlling techniques.

For monitoring and controlling of plant agriculture to be effective, communications and information management technologies need to be further diffused into agriculture. The lack of adequate software development to fully utilize the new technologies will be overcome as universities and private firms fill obvious voids. The capital investments required by farmers must not create barriers to widescale adoption of the technology. The greatest inhibiting factor will be the ability of the individual farmer to grasp the complete significance of using monitoring and controlling techniques for plant agriculture. Crops most likely to have these techniques applied include corn, cotton, soybeans. Horticultural crops that have high production costs may be neglected because the potential payoff of using sensors in these highly managed applications does not presently justify the development costs.

In order to collect adequate information it may be necessary for farmers to incorporate data collection devices on their farm machinery. As in the earlier example of the corn planter, the farmer could have a continous record of fertilizer and planting data that could be taken to the main computer for storage and subsequent updating and analysis of farm files.

Farmers that adopt monitoring and controlling techniques for plant agriculture will be producing higher quality crops, obtaining premium prices and engaging in more profitable farming activities. The very fact that a large production segment of agriculture is using these advanced techniques will serve to apply pressure to those less advanced segments to catch up. The tendency will be to squeeze the farmer that is not a forward thinker. The converse, however, will be to enable farm operations that are at the margin to become profitable through the efficient utilization of the available resources. The effective use of purchased inputs and the timely marketing of output will achieve the most favorable product prices and benefits for both the farmer and the consumer.

References for Monitoring and Controlling Technologies for Plants

Angell, J.B., Terry, S.C., and Barth, P.W., "Silicon Micromechanical Devices", Scientific American, pp 44-55, April, 1983.

Battelle Columbus Division, discussions with sensors experts, Jan., 1984.

Bunn, J.M., Dunlap, J.L., and Hammond, G., "Energy Efficient Drying Through Computer Control", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Firestone, L.M. and McClure, W.F., "VLSI Architectures for Image Processing", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, Il, Dec. 11-13, 1983.

Hirsch, M., Dean, S.P., Lice, B., et al, "Distributed Microprocessor Systems for Soil and Well Monitoring", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Ksiazek, T.F., and Funk, R.C., "Storage Management Using Distributed Processing", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

McConnell, R.C., Elliot, K.C., Blizzard, S.H., et al., "Electronic Measurement of Tree-Row-Volume", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Moerdyke, D.D., "The Utilization of a Programmable Controller for Process Control of a Fertilizer Blend Plant", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Persson, G.W. and Churchhill, R.W., "Automatic Computer Control of Grain Drying and Aeriation", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, December 11-13, 1983.

Warnock, W.K. and Wofler, P.D., "Microprocessor Control of a Cross-flow Grain Dryer Test Unit", Agricultural Experiment Station, University of Arkansas, Fayetteville, Arkansas.

Van Straalen, E., Kreisil, H., and Peterson, C.L., "Microcomputer Data Acquisition and Control for Sugarbeet Storage", Paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Background Paper No. 25

Telecommunication

Battelle Columbus Laboratories
Columbus, Ohio

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

TABLE OF CONTENTS

Page

INTRODUCTION 1

STATE-OF-THE-ART 2

Digital Communication. 4

Fiber Optics. 4

Personal Computers. 5

Videotex and Teletex 6

Value Added Networks 8

Integrated Services Digital Network 9

Remote Sensing 10

Selected Examples of Telecommunications State-of-the-Art in Agriculture. 12

MAJOR BREAKTHROUGHS NEEDED. 15

INSTITUTIONAL ARRANGEMENTS. 17

MAJOR IMPLICATIONS 18

REFERENCES 21

LIST OF TABLES

Table 1. Summary of Telecommunication Presentation Types and Transmission Medium and Rates. . 3

SUMMARY FOR TELECOMMUNICATIONS

Anticipated future developments in telecommunications are digital communications, fiber optics, personal computers, videotex and teletext, value added networks, remote sensing and Integrated Services Digital Network. The evolution of telecommunications has been driven by the different requirements of various users, such as the amount of information to be transmitted, the distribution, transmission quality and the type of information presented (voice, text, graphics).

Digital communications refers to electronic messages that are transferred in discrete elements, as opposed to a continuous wave. Digital communications uses low cost computing equipment for network control, switching and signal handling.

Fiber optics uses light rather than electricity to transmit the signal. Fiber optics requires less amplification and is not affected by electronics noise.

Personal computers are penetrating agricultural markets. Telecommunications networks for personal computers are available from firms such as CompuServe, The Source and others.

Videotex is a public two-way interactive service that provides consumers on-line access to information. The interaction mode of videotex makes it feasible to carry information and data for users.

Value Added Networks will be a major element in the future communications environment. The "added" services of these networks are protocol, code, format conversions, gateways to other networks and electronic mail services.

Integrated Services Digital Network is a digital telephone network that can simultaneously transmit digital voice, data and a variety of other services. This system enables data to be transmitted over telephone lines by audio modems.

Remote sensing is the recording and analysis of electromagnetic radiation from the earth to estimate crop yields, monitor surface water, soil erosion, climate conditions and crop or vegetation stress from insects or disease.

Many of the telecommunications technologies that will be used by agriculture during the next 5 to 10 years are already operational within the present telecommunications network. The biggest problem is the ability to provide service to rural America on a cost effective basis. A major telecommunications trend will be the use of teleport technology. Teleports will provide linkages to multiple telecommunications services (satellites) and be accessible on a regional basis.

The major implication of agriculture using telecommunications systems will be to provide farmers with a greater resources for decision making. To access remote computer services, on line data bases, videotex and teletex systems will require that farmers be better organized in how they think about their operation, how they gather information and the way the information will be used in decision making.

On line marketing services should be capable of reducing marketing costs by eliminating terminal market and other marketing charges, as well as reducing transportation costs. The system provides greater exposure and information to buyers and sellers.

For farmers to market in a timely manner has substantial revenue implications. Where videotex systems are used to link buyers and sellers, timely marketing can occur resulting in potentially higher revenues to farmers.

TELECOMMUNICATIONS

Introduction

The usefulness of information is not just dependent on its accuracy, but also on its timeliness. Telecommunications is a rapid, but frequently costly, form of communication. This paper will discuss the current-state-of-the-art and anticipated future developments in telecommunications, emphasizing the following technologies:

- Digital communication
- Fiber optics
- Personal computers
- Videotex and teletext
- Value added networks
- Integrated services digital network
- Remote sensing.

Major technological trends in telecommunications include:

- Transition from analog signal to digital signal switching and transmission, allowing simplified integration of computers to telecommunication networks
- Integration of the currently evolving different services (or different kinds of telecommunication) into a single network
- Providing small, low-cost computing equipment for signal processing and handling using VLSI (very large-scale integrated) circuit components

- Providing low-cost, high transmission rate media, such as fiber optics
- Increasing coverage of networks and easing access to networks by means of communication satellites.

State-of-the-Art

The evolution of telecommunication has been driven by the different requirements of users, which has led to the emergence of different telecommunication technologies. Requirements resulted from the amount of information to be transmitted, its distribution, transmission quality, and the type of information presented (such as voice, text, graphics, etc.). Table 1 summarizes the most important types of information presentation, the transmission medium for that information and an indication of the minimum rate of transmission for satisfactory service

In telecommunications jargon, "smallband" is associated with low rates of transmission, such as telephone-type lines (two-wire or four-wire) with bandwidths in the order of several kHz. "Broadband" refers to high rates of transmission (50-200 MHz) such as rates necessary to transmit TV signals. "Medium" bandwidths are in the order of 30 to 100 kHz and would be most effective to transmit telefax, facsimile, and data.

Recent developments impacting electronic communications will be highlighted in the discussion of digital communications, fiber optics, personal computers, videotex and teletext, value added networks and integrated services digital networks.

TABLE 1. SUMMARY OF TELECOMMUNICATION PRESENTATION TYPES AND TRANSMISSION MEDIUM AND RATES

Presentation Type	Transmission	
	Medium	Rate[a]
Voice	Telephone	Low
Text	Telex, teletext Videotex, electronic Mail	Low Medium
Graphic, Still Frame Video	Facsimile, telefax Teleconference	Low, medium Medium
Data	Value Added Network Datel Telemetry	Low to Medium
Full Motion Video	Videoconference, Picture telephone	High High

Source: Battelle Columbus Division

(a) Rate indicates minimum transmission rate required for satisfactory transmission of a particular presentation type on a given medium.

Digital Communication

Digital communication refers to electronic messages which are transferred in discrete elements (bits) as opposed to a continuous wave (analog signal). The major advantages of digital communication are:

- The use of low-cost computing equipment for network control, switching and signal handling
- Ease of integrating voice, text, and data transmission.

The major advantages of analog communication is a much lower bandwidth requirement for voice and video telecommunication. Digital switching and transmission equipment currently is being installed as replacement equipment by Bell Telephone operating companies.

Problems. A major problem with implementation of digital communications is the large capital investment needed to replace the massive volume of existing analog switching, transmission, and terminal equipment.

Fiber Optics

Fiber optics uses light as the transmission signal on a glass fiber, as compared to using electricity as the transmission signal on traditional copper pair-wire telephone lines. Fiber optics is a digital transmission media, which operates using a semiconductor light source (laser or LED) emitting light pulses over a low-loss, low-dispersion glass or plastic fiber.

Fiber optical cable is a high capacity (bandwidth) transmission medium which may replace existing lines - coax, two-wire, four-wire, microwave and satellite in some cases. The reasons for this changeover would include: decreased cost, reduced cable size (per unit of capacity), less repeater equipment, and no interference from electronic "noise". Fiber optical cables currently are being installed, as replacement media for long distance, heavy transmission telephone lines.

Problems. As with digital transmission, a major problem with fiber optics is the amount of new equipment that would have to be installed to achieve a significant penetration into the telecommunication market. A related problem is the cost of optical fiber because of relatively low production levels. Other problems are difficulties with splicing optical cables and the need for optical/electrical interfacing (to fit into existing telecommunication networks).

Personal Computers

A major requirement for widespread use of telecommunication for text and data transmission is the increased market penetration of low-cost devices that can access data transmission networks. Probably the most important of these devices are personal computers. Personal computers are being purchased in record numbers for both home and business use. The increasing penetration of personal computers into private residences indicates that in the future, an increasing number of citizens will gain access to a data and text telecommunications network. Personal computers will play a major role in the electronic transfer of text, graphics, and data.

Telecommunication networks for personal computers are currently available from firms such as CompuServe, The Source, and others. CompuServe, Columbus, Ohio, has over 100,000 subscribers nationwide that access a variety of services by the Bell Telephone Network using personal computers and asynchronous modems. CompuServe provides a large variety of services, including numerous information and data services, gateways to perform banking transactions, and electronic mail.

Problems. The rapidly changing economics is a primary problem. Costs for computer hardware and peripherals is declining rapidly, but costs for software are still high as is the cost for user time. Computers need to become more user friendly and more software needs to be directed toward specific end user applications. Compatability with other computer systems can be a problem, but value added networks are providing services to surmount this problem.

Videotex and Teletext

Videotex is a public two-way (interactive) service designed to provide consumers on-line access to information. Teletext is a one-way broadcast system which provides information to consumers.

Videotex is a truly interactive service which users generally access by the telephone network. In some instances access is gained by using two-way cable television networks.

Because of the two-way nature of videotex, the potential data accessible by the user is virtually unlimited. Users also may input information for others to access. The size of the videotex data bases is constrained only by the storage capacity of the central computer. In teletext, the entire data base must be transmitted every 10 to 20 seconds,[1] so the size of the data base is determined by the data capacity of the communication channel.

Also, because of the interactive nature of videotex, it is feasible to carry information and data of more specific interest to subgroups of users, for example, agriculture. Users may make reservations at parks or campgrounds, place orders for products, or carry out financial transactions. Users also are permitted to create their own data bases for such things as newsletters to special interest groups. Those desiring the information or data access the system by using a special code.

Typically, videotex is implemented on a central computer and is accessed with a special terminal. Some systems, such as those offered by CompuServe and The Source, allow access by home computers or even dumb (non-computing) terminals. Others require very specific video display terminals programmed for a specific format to display text and graphics as, for example, the advanced graphics capability available to northeast farmers through "Grassroots" service. Still others require a small decoder with a numeric keypad and an attachment to a standard television receiver for display purposes.

---

[1] If buffer storage is included with the Teletext receiver, a much greater amount of text can be transmitted.

Problems. The cost and development time of setting up a videotex/teletext network is an obstacle to wide scale adoption of this technology. In-home terminals are expensive and no standard transmission protocol has been accepted in the United States. In presently implemented systems there is no capability to transmit full motion or still frame video (pictures) during interactive transmissions.

Value Added Networks

Value Added Networks (VANs) will be a major element in the future communications environment. The "added" services of these networks are protocol, code, and format conversions, gateways to other networks, and electronic mail services. These services enhance compatibility between different types of terminals, word processors, and computers.

For the past several years, the public VAN market has been virtually dominated by GTE Telenet and Tymnet. Recently, however, over 20 new competitors have entered the market. Major among these competitors are:

- IBM which has the Information Network linking 7 major U.S. cities using leased AT&T lines, and the IVANs nationwide network for insurance agencies. Both services are mainly for IBM computers and hardware.

- AT&T is developing AIS/NET 1000 service, which is compatible with over 80 percent of the computer terminals currently in use.
- GTE's Telenet and Tymnet have between them local access in approximately 400 cities, and both networks support a variety of terminals and services.

There are a wide variety of networks directed specifically toward agricultural applications. Among the many services are AGNET, CRIS, FANI, SCAMP and TELEPLAN.[2] The types of services provided include market advice, market data, weather, electronic mail, electronic trading, pest control information, farm management advice and problem solving software.

Problems. Major problems with VANs include a lack of high bandwidth or digital transmission capability, and network incompatibility with only certain types of personal computers.

Integrated Services Digital Network

An Integrated Services Digital Network (ISDN) is a digital telephone network that can simultaneously transmit digital voice, data, and a variety of other services. The availability of digital channels will allow digital devices, such as terminals, personal computers, and word processors, to plug into the network without the necessity of modems, and the data rate available will be many times what is currently available on voice grade lines. Currently, asynchronous communications over telephone dial-up lines (smallband) generally is limited to 1200 bps data rate, which equates to approximately 1-1/2 single spaced typed pages per minute (4000 characters/page, approximately). An ISDN channel (medium band) would allow a 32,000 or 64,000 bits per second data rate, equating to a page rate of 80 or 160 pages per minute, respectively. The full-scale implementation of digital telephone networks is still a number of years in the future. In the meantime, data communications over analog telephone lines via modems will increase, due to decreased cost of modems and increased demand for data communications.

---

[2] The application and use of these services were discussed in the paper on Communications and Information Management.

Problems

The major problems with ISDN include the lack of an existing digital network, the lack of an interface or communication standard, and the need for 50-100M bit/sec digital transmission rate for video.

Remote Sensing

The recording and analysis of electromagnetic radiation from the earth is remote sensing. The radiation could be microwave, visible light or infrared radiation. Remote sensing can be conducted from aircraft or satellite. Early remote sensing satellites launched in the 1970's, Landsat 1, 2 and 3, were capable of providing image data every 18 days, weather permitting, at a minimum resolution of 1.1 acres. The launching of Landsat 4, in July, 1982 increased the minimum resolution to 0.2 acres.

Information from remote sensing satellites can be used to estimate crop yields (in conjunction with ground intelligence), monitor surface water, soil erosion, climate conditions and crop or vegetation stress from insects or disease. However, disadvantages with remote sensing were infrequent coverage and long delays in making data available after it was collected.

Recent advances in automated guidance systems have enabled advanced computers to fly airplanes in a fixed path, for example over a number of farm fields (Jackson, 1983). The use of polar orbiting satellites for monitoring appears to be practical for obtaining long-term information, but of little value for obtaining hour-to-hour information.

As an aid to farm management, current remotely sensed images of fields may soom be available for transmission over existing agricultural information systems. Widespread dissemination of images by service companies over information networks may have to await better medium rate transmission systems. Beyond 2000 intelligent systems will analyze multispectral images and provide diagnosis.

Problems. A primary problem in using agricultural remote sensing is that insufficient ground-based data are available to develop the necessary expert systems to permit farmers to use the information on present farm computer systems. To be useful for farm management decisions, the data must be timely, preferably a real-time basis, and in a format that will permit farmers to use the information.

Selected Examples of Telecommunications State-of-the-Art in Agriculture

An example of extensive tests of videotex for agricultural use was the American Farm Bureau (AFB) experiment of American Agricultural Communications Systems, Inc (Bissell, 1983). The purpose of the system was to serve the communication and information needs of national, state and county Farm Bureaus, as well as individual Farm Bureau needs. Planning for the system began in 1976, with one year of test programs between July, 1981 and 1982. The states of Ohio, Michigan, Illinois, Iowa, Arkansas, Georgia, and South Carolina participated in the pilot test programs.

A primary advantage of the AFB videotex experiment was the ability to access and utilize information from members in different parts of the country. For example, farmers would be able to get in touch with grain dealers who wanted to purchase grain.

The results of the test program were mixed. A positive sign was that the Ohio Farm Bureau has gone commercial with its program. Several participating farmers indicated they improved overall farm revenues by as much as $17,000 by using the system. Michigan also is proceeding to commercialize the system; however, a detriment to state's wide use of videotex is the relatively small number of farmers that have computers. Until a larger number of farmers acquire computers, the videotex system will have limited use.

At the other extreme is the reaction of the Illinois Farm Bureau (IFB). The IFB already had been providing a market advisory service by WATS lines as early as 1975. By 1977 the daily market information system was updated 15 to 16 times per day. By 1980, IFB was sending digital data on radio subcarriers that could be displayed in video form. The service was distributed to radio stations on satellite and covered the northern third of Illinois. Therefore, Illinois farmers were familiar with a more advanced system that could be provided at less cost than the AFB experimental program. It is understandable why some Illinois farmers were less than enthusiastic with the AFB system. However, the farmers participating in the experiment felt the information from the AFB system was a valuable contribution to their overall information needs.

Examples of other telecommunications systems in agriculture are many (Chartrand, 1983). For example, the University of Nebraska AGNET uses a computerized service in conjunction with training assistance from the county extension offices. The service began in 1975 and is available to farmers in Montana, North Dakota, South Dakota, Wyoming, and Washington. The oldest computerized farm program was developed by Michigan State University in 1963 under a grant by the Kellogg Foundation. TELFARM provides farm accounting systems, linear programming models, and financial planning models. However, TELEFARM is not particularly user friendly and requires above average computer skills to be effectively used on an individual basis.

Michigan State University also uses its COMNET communications system for dispensing information generated by the FAHRMX system, a Food Animal Health Resource Management system. This integrated system provides veterinarians and dairy herd managers with a comprehensive system that enables collection, analysis and storage of production, animal management, health and financial data (Mather, 1983).

There are a number of experimental electronic marketing services for livestock. The University of Illinois' electronic trading for wholesale meat, CATS and CATTLEX, Texas A&M University's system for electronically trading cattle are primary examples. The National Electronic Marketing Association (NEMA), owned by the National Livestock Producers Association (NLPA), is a time-share network that links individuals by leased telephone lines to a master computer in Los Angeles. The NEMA system was an outgrowth of the system the Virginia Department of Agriculture developed under a USDA grant. The auctions have been very successful in increasing competitive bidding for livestock.

Electronic marketing systems reduce animal stress, transportation expenses and marketing expenses. The animal never leaves the farm until a new home has been found or the animal has been sold for slaughter. The marketing system has been highly successful for lambs and hogs, but less successful for feeder cattle where lack of bidding competition has limited system success.

Major Breakthroughs Needed

Much of the telecommunications technologies that would be used by agriculture during the next 5 to 10 years are already in place in various parts in our telecommunications system. A large problem appears to be the ability of providing a cost-effective service to rural America. In many rural communities the telephone switching equipment and line voltage requirements may be unable to provide sufficient power for transmission of digital computer information. For example, it is not uncommon in rural areas, particularly in remote rural areas, for farmers to have a telephone party line system. If an individual from one farm family were transmitting or receiving information on the computer, and another farm family on the same telephone line picked up the telephone, line voltage could drop to the point where the computer would drop the connection or the signal would become garbled and the information transmitted unusable. To bypass local telephone and party line system problems, broadband transmitting to rural areas would be an effective albeit costly solution.

Fiber optic systems for transmitting and switching large amounts of digital information are a potential solution for solving many of the capital investment problems created by the thousands of miles of telephone wires strung throughout rural America. The major obstacle to the use of fiber optic systems is to design a network which could provide the technological capability on a cost effective basis. A cost effective fiber optic (or other medium bandwidth) system would enable rural telephone companies to provide digital communications service.

The use of the personal computer on the farm will increase markedly during the next decade. As information system networks presently available are used more extensively, costs will decline. A primary problem with real time use of personal computers is the cost of using conventional telephone lines. It may be more cost effective for the user to send data to a major station (in a metropolitan area) where it could be processed (batch processed) and subsequently returned to the user. While a batch processing network would require additional time (possibly resulting in some financial loss), this interim step would solve many of the current problems of rural data transmission. On an overall cost basis, batch processing may be the most effective means of combining the capabilities of the personal computer and current telecommunications networks with the information requirements of the farm.

A major telecommunications trend of the future will be the application and use of teleport technology. Teleports will provide linkages to multiple telecommunication services (i.e., satellites) and be accessible on a regional basis. Teleports will be capable of handling all types of telecommunications and function as both primary and relay stations. Service probably will be for a radius of several hundred miles.

Timing to Commercialization. The use of broadband telecommunications in rural areas will be very limited during the next 5 to 10 years. There may be some cooperative ventures among agriculturally related enterprises; however, due to the large capital investment needed to implement advanced telecommunication systems, the costs for new systems in rural areas presently do not justify the anticipated limited use by farmers.

Fiber optic systems are beginning to be used by telephone companies in major metropolitan areas. It is hypothesized that rural areas will not experience the use of fiber optics technology in telecommunications systems until the early part of the 21st century.

The use of information systems network linkages by farmers will continue to occur rapidly for personal computers, teletext and videotex. The greater computational capabilities of personal computers will reduce data transmission problems in rural areas for a short time.

The major barrier to the adoption of videotex equipment has been the lack of in-home devices to connect and receive transmissions. As connection costs decline and more farmers purchase personal computers, use of videotex systems will increase and become more cost effective on an individual basis.

Institutional Arrangements

The pioneers in incorporating videotex and value added networks in U.S. agriculture have been the American Farm Bureau and the state Farm Bureau organizations, such as the Illinois Farm Bureau, the Michigan Farm Bureau, and the Ohio Farm Bureau and land grant universities, particularly the University of Nebraska and Michigan State University. A recent announcement by IBM, CBS, Inc., and Sears Roebuck and Company stated their intent to establish an extensive national videotex service offering software, catalog shopping and financial services (Hillkirk, 1984). As other information systems are being developed, such as electronic marketing systems for livestock and commodities, more universities are becoming actively involved in establishing and monitoring the development of these programs.

The incorporation of the advanced telecommunications technologies, such as fiber optics, will require that agricultural institutions cooperate more with the private sector, particularly telecommunication companies and the private firms that are involved in providing on-line data bases and communication, for example, CompuServe. The effort between the public and private sectors will need to be cooperative to achieve the vast potential of these systems.

Major Implications

The major implication of increased use of telecommunications systems by agriculture will be to provide farmers with a greater variety of resources to use for decision making. As micro (on farm) management information systems are installed and used by farmers, there will be a greater amount of information available to help the farmers to manage on-farm resources.[3] Having the capability to access a broad range of data bases and to use this information base, should make the farmer a more effective manager.

---

[3] A total on-farm management information system is discussed in the paper Communications and Information Management.

The access to remote computer services, on line data bases, and videotex and teletex systems will require that farmers be better organized in the way they think about their operation, the way they gather information and the way the information is to be used in decision making. An on-farm management information system need to have enough data collected to drive the packaged programs available from on-line information services and used for solving on-farm management problems.

On line marketing services such as those used for marketing livestock will provide buyers and sellers with a quick and efficient means of arriving at market prices. However, when describing a product, such as an animal, on a video system, the computer auctioneer needs to provide very detailed descriptions so that both buyers and sellers have a full understanding of the product being offered. The pilot projects have indicated when descriptions are comprehensive, misunderstandings are not a problem.

Livestock computer marketing systems should be capable of reducing marketing costs, reducing transportatin costs, and providing greater exposure and information to more buyers and sellers. A Longer term impact may be an increase in the quality of livestock because of the greater competition for high quality animals.

Remote sensing information probably will have its greatest impact in improving the quality of weather data and information regarding the stress of crops. Receiving timely weather information can assist farmers in both planting and harvesting activities and reduce total production costs.

Remote sensing information also could be used to increase information on crop status throughout the year. For example, timely information regarding the status of crops during the growing season may help to reduce the wide price swings associated with some crop commodities.

The ability to market in a timely manner has substantial revenue implications to farmers. Where videotex systems are used to link buyers and sellers, timely marketing can occur resulting in potentially higher revenues for farmers. On the other hand, forward contracting and hedging using the futures market may increase because farmers have the ability to keep track of commodity prices, futures prices and analyze prices to decide the optimum time for marketing commodities.

A longer term implication of increased telecommunications services to the rural communities will be to bring those communities more in focus with the activities and the available services in metropolitan and major metropolitan areas. Telecommunications linkages will provide the rural community with better information thereby enabling the rural community to more effectively utilize its leisure and productive time.

References for Telecommunications

Battelle Columbus Division, discussions with selected technical experts, Jan., 1984.

Bissill, K., "American Farmers: Pioneers in Videotex", Today, April, 1983, pp 12-17.

Chartrand, R.T., Carr, A.B., and Miller, N.R., "Getting Information to the Farms", ASIS Bulletin, Feb., 1983, pp 10-16.

Cummings, M.L., "The Computer Connection - Plugging Microcomputers Into Your Market", Agri Marketing, 22(1):36-44, Jan., 1984.

Effertz, N., "Computers Light Up Livestock Auctions", Farm Journal, pp 20-22, Dec., 1983.

Hillkirk, J., "Videotex Partners", USA Today, p 1, Feb., 15, 1984.

Jackson, R.D., "Remote Sensing of Vegetation Characteristics for Farm Management", paper presented at the Society of Photo-Optical Instrumentation Engineers Technical Symposium East '84, Arlington, VA, April 30, 1984, SPIE Paper No-475-10.

Jackson, R.D., and Youngblood, J.W., "Agriculture's Eye in the Sky", Crops and Soils Magazine, pp 15-18, Oct., 1983.

Maher, P., "Plugging Into On-Line Databases: A World of Information at Your Fingertips", Business Marketing, pp 62-68, 85-86, Oct., 1983.

"The Management Difference: Future Information Needs of Commercial Farmers and Ranchers", Arthur Anderson and Co., Chicago, IL, 1982.

Marking, S., "Zoom In On Crop Stress", Soybean Digest, pp 28-29, April, 1982.

Mather, E.C., and Bartlett, P.C., "Electronic Transfer and Processing of Biological Data into Usable Animal Health Information", paper presented at the National Conference on Agricultural Electronics Applications, Chicago, IL, Dec. 11-13, 1983.

Mauzey, M.L., "Reaching Your Market Through Computers", Agri-Marketing, 21(2):16-20, Feb., 1983.

Merrill, J.L., "Strategies for the Twenty-First Century", Agriculture in the Twenty-First Century, J.W. Rosenblum, ed., (New York: John Wiley and Sons, 1983) pp 196-202.

Pelton, J.N., "The Future of Global Satellite Communications: Space Odyssey 2000", Communications and the Future: Prospects, Promises, and Problems, H.F. Didsbury, Jr., ed., (Bethesda: World Future Society, 1982) pp 74-77.

Production Credit Associaton, Agriculture 2000: A Look at the Future, Battelle Press, (Columbus: Battelle Press, 1983).

Tydeman, J., H. Lipinsky, R. Adler, et al., Teletext and Videotex in the United States, (New York: McGraw-Hill Publications Company, 1982).

Background Paper No. 26

Labor Saving Technology

Battelle Columbus Laboratories
Columbus, Ohio

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

LABOR SAVING TECHNOLOGIES

Summary

United States labor requirements for livestock, poultry, and dairy production declined by 60 percent from 1965 to 1981, while labor hours for crop production declined by 28 percent during this same time period. Labor costs as a percentage of total crop values for field crops such as corn, wheat, and soybeans generally are less than 8 percent of the crop's total value. However, for horticultural crops, the cost of labor as a percentage of total crop value may range from 20 to 60 percent.

The development of large scale confinement livestock and poultry operations have significantly reduced labor requirements through developments such as automatic feeding, waste disposal, and egg collection. Labor requirements for field crops have declined due primarily to farm equipment such as tractors, combines, and tillage equipment becoming larger.

Two major concepts are discussed in this paper--(1) mechanized fruit and vegetable operations, (2) robot farming. Mechanization of horticultural crops refers to substitution of machinery and electronics for hand labor in planting and harvesting the crops. In addition to reducing labor requirements, mechanization can provide cost and quality advantages to the grower through more timely harvesting of the crop. Robot farming refers to the conduct of farming operations without human controllers. Agricultural robots can be mobile or fixed in one position.

Many horticultural crops, especially vegetables, are not intensively mechanized for various reasons. Crops for the fresh market are too delicate to be handled by currently available mechnical means. Many vegetables do not ripen at the same, thus making selective harvesting necessary. The large capital investment for mechanization also reduces the growers flexibility to change from one market to another. Mechanical harvesting of vegetables for processing is much more common than mechnical harvesting of vegetables for the fresh market. Examples of mechanical harvesting systems are described for major crops such as potatoes, tomatoes, dry onions, oranges, grapes, and deciduous fruits.

Use of robotic applications in agriculture is likely to be centered on high value, labor intensive crops such as oranges. Current robotic systems are too costly and too slow to be competitive with hand picking. However, by 1990, it is conceiveable that costs of robotic technology could be reduced, and the speed of operations increased, to the point where such technology would be economically competitive.

Robotics also may have potential applications to animal agriculture such as checking calving and farrowing, identifying estrus, managing feeding, determining pregancy, assistance in manure handling, and assistance in animal slaughter and carcass fabrication.

Future labor replacement in agriculture likely will involve some aspect of electronics technology. Many of these electronic technologies are offshoots from military or aerospace applications, and must be adapted to agricultural environments. The rate of development depends upon the ability of agricultural and electronics technologists to communicate effectively to arrive at realistic concepts, objectives, and schedules. Reliability and the ability to withstand wide a variety of environmental conditions are essential for agricultural applications of electronics technology. Also, it is essential that electronic technologies exhibit favorable cost/benefit ratios for widespread commercial adoption.

Decreasing emphasis is being placed on spending public funds for mechanization research. The private sector is likely to continue to be one of the most effective sources of new mechanical and electronic technologies that replace agricultural labor. Mechanical harvesting equipment for horticultural crops is built primarily by short-line manufacturers. Because the total production of each piece of harvesting equipment is limited, these manufacturers do not have large research and development budgets, and frequently rely on a combination of public research results, growers' inventiveness, and their own ideas to development new and improved equipment.

Many of the new electronic technologies may not necessarily affect the quantity of labor as much as the quality of labor. On the one hand, changes in the machine operations may be made automatically, thus requiring a less highly trained operator to respond and make corrective changes in machine performance. On the other hand, skilled service support must be available to maintain the complex machinery systems.

LABOR SAVING TECHNOLOGIES

Introduction

The emphasis in this paper is on labor saving technologies as they apply to fruit and vegetable production, due to these crops relatively high labor requirements.[1] For example, for various horticultural crops in Ohio, the estimated cost of labor as a percentage of the total crop value may range from about 20 percent for cabbage to 55-60 percent for staked tomatoes and pickling cucumbers. By contrast, labor costs as a percentage of total crop values for field crops such as corn, wheat, and soybeans, is about 4 percent, 8 percent, 7 percent, respectively. Labor requirements for vegetables, fruits, and nuts accounted for over 19 percent of the total labor hours in all farm work in 1981. However, vegetables, fruits and nuts account for less than 11 percent of the value of U.S. farm production (Figure 1). On this basis, there appears to be significant opportunities to reduce food costs by increased mechanization of fruit and vegetable production.

Table 1 indicates that more rapid advances in labor saving technologies have occurred in the livestock sector compared to crops. United States labor requirements for livestock, poultry, and dairy

---

1. Mechanization advances in field crops such as grain and forages are discussed in another paper authored for the Office of Technology Assessment, entitled "Crop Separation and Cleaning Technologies".

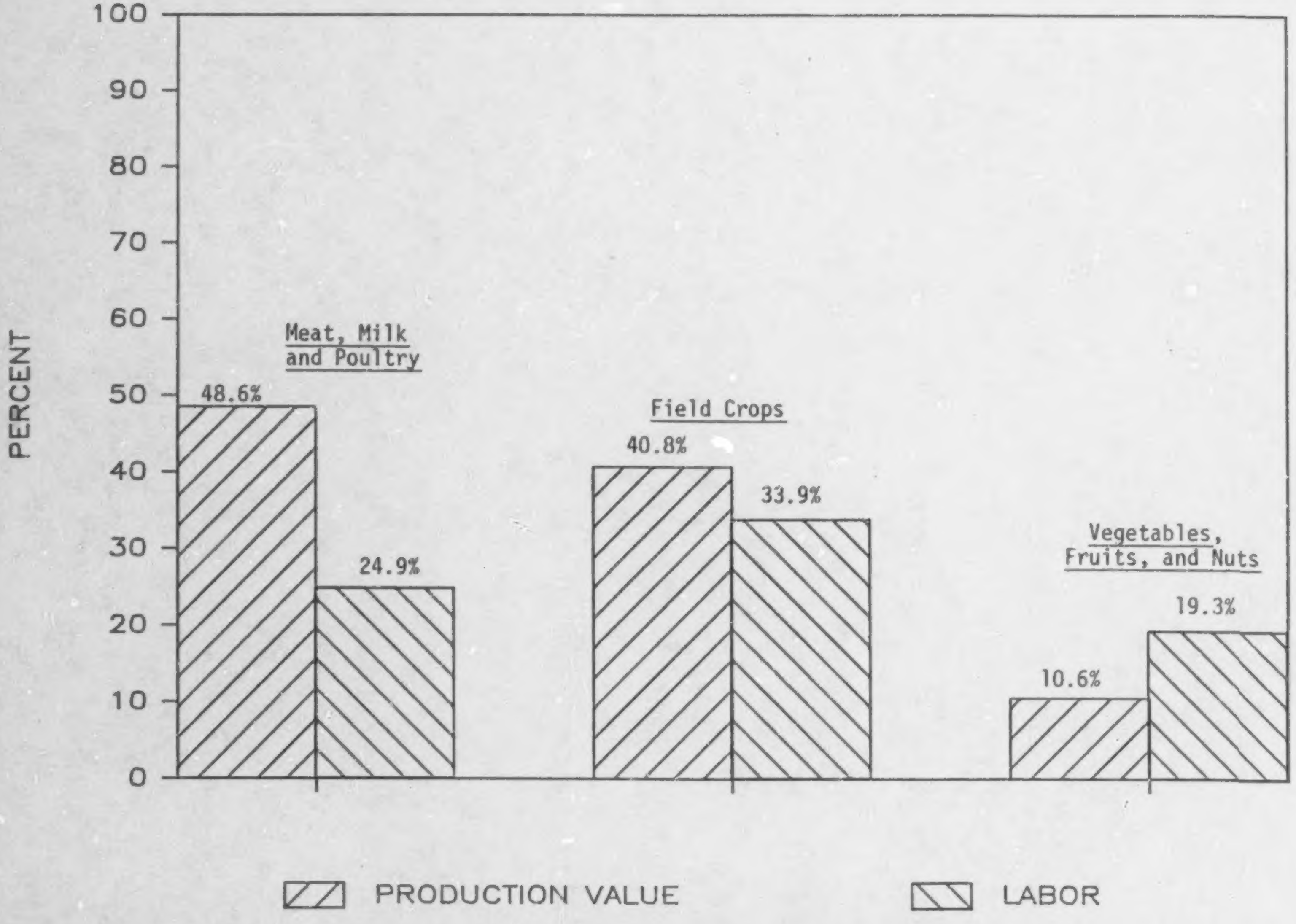


FIGURE 1. VALUE OF PRODUCTION AND LABOR HOURS' %
BY COMMODITY GROUPS, USA, 1981

TABLE 1. LABOR: TOTAL HOURS USED FOR FARM WORK, BY ENTERPRISE GROUPS.

	1965	1970	1975	1981	% Change 1965-81	% of Total Farm Work Hours 1965	% of Total Farm Work Hours 1981
	(Million Hours)				%	%	%
Livestock and Livestock Products							
All[1]	2,969	2,344	1,701	1,189	(60.0)	40.5	28.4
Meat Animals	1,107	997	731	509	(54.0)	15.1	12.2
Milk Cows	1,250	817	568	357	(71.4)	17.0	8.6
Poultry	444	373	251	178	(59.9)	6.1	4.3
Crops							
All[2]	3,416	2,788	2,626	2,446	(28.4)	46.6	58.6
Feed Grains	502	425	377	342	(31.9)	6.8	8.2
Hay & Forage	410	339	287	238	(42.0)	5.6	5.7
Food Grains	176	152	222	234	33.0	2.4	5.6
Vegetables	407	359	355	317	(22.1)	5.5	7.6
Fruits & Nuts	454	452	472	484	6.6	6.2	11.7
Sugar Crops	85	74	73	62	(27.1)	1.2	1.4
Cotton	482	244	105	79	(83.6)	6.6	1.9
Tobacco	468	308	286	226	(51.7)	6.4	5.4
Oil Crops	203	205	219	234	15.3	2.8	5.6
Farm Overhead or Maintenance	950	764	644	539	(43.3)	13.0	12.9
All Farm Work	7,335	5,896	4,971	4,174	(43.1)	100.0	100.0

---

[1] Includes wool and minor livestock not specified in table.

[2] Includes seeds and minor crops not specified in table.

Source: U.S. Department of Agriculture, Agricultural Statistics, 1982, Table 613; and Agricultural Statistics, 1983, Table 603, page 425.

production declined by 60 percent, from 2.97 billion hours in 1965 to 1.19 billion hours in 1981. Labor hours also have declined for crop production, but by only 28 percent during the 1965-1981 time frame (3.42 billion hours, 1965 to 2.44 billion hours, 1981). Table 2 indicates labor hours per unit of production for various crop and livestock commodities, along with labor costs expressed as a percentage of total production value in 1980/81. Significant declines in labor hours per unit have occurred for all commodities over the past 40-45 years. With the exception of beef, less than one-half hour of labor is required to produce 100 units of product output for all livestock categories (sheep being excluded from the analyses). Modern large scale confinement livestock operations lend themselves to automatic feeding, automatic waste disposal, and automatic egg collection. These developments have been responsible for decreasing the total hours of labor used for meat animal production in the United States. A fully mechanized one-person operator with adequate on-call support can handle as many as 2,000 feeder cattle, 2500 slaughter hogs, 50,000 laying hens, or 250,000 broilers annually.

Labor requirements for field crops have declined as a result of tractors, combines, and tillage equipment becoming larger, even though the numbers of these units also have declined. For example, in 1965 there were 4.78 million tractors in the United States compared to 4.65 million in 1982; however, total tractor horsepower increased from 176 million in 1965 to 275 million in 1982. The total number of grain combines declined by more than 25 percent between 1965 and 1982, even though total grain area harvested increased by more than 40 percent during this period. Total production and productivity increased because the larger equipment enabled

TABLE 2. SELECTED CROPS AND LIVESTOCK: LABOR-HOURS PER UNIT OF PRODUCTION AND RELATED FACTORS, 1935-39, 1955-59, 1977-81

		1935-39	1955-59	1977-81	Labor Cost % of Production Value, Estimate 1980-81
Crops					
Corn for Grain	(Hours per 100 Bus)	108	20	3	4.1%
Sorghum Grain	(Hours per 100 Bus)	102	20	6	8.8%
Wheat	(Hours per 100 Bus)	67	17	8	7.9%
Hay	(Hours per Ton)	9.1	3.7	1.4	7.8%
Potatoes	(Hours per Ton)	20	6	3	9.8%
Sugarbeets	(Hours per Ton)	8.4	2.9	1.2	12.1%
Cotton	(Hours per Bale)	209	74	6	7.1%
Tobacco	(Hours per 100 lbs)	47	31	12	29.8%
Soybeans	(Hours per 100 Bus)	64	23	12	6.8%
Livestock*					
Hours per Cwt.	Milk	3.4	1.7	0.3	8.6%
Hours per Cwt.	Beef	4.2	3.2	1.2	7.6%
Hours per Cwt.	Hogs	3.2	2.4	0.4	3.8%
Hours per Cwt.	Broilers	8.5	1.3	0.1	1.4%
Hours per 100	Eggs	1.7	0.9	0.2	15.5%
Hours per Cwt	Turkeys	23.7	4.4	0.4	3.9%

*Live-weight production

Source: U.S. Dept. of Agriculture, Agricultural Statistics, 1982, Tables 592 and 593; page 411 farmers to perform operations in a timely manner with reduced risks and lower losses.

This paper will discuss changes that are occurring or expected to occur as a result of mechanizing the labor intensive operations of specialty horticultural crops, grain and livestock production. Primary emphasis is placed on two lines of research:

- Mechanized fruit and vegetable operations
- Robot farming.

Mechanization of harvest operations for fruit and vegetable crops refers to the substitution of machinery and electronics for hand labor. In most cases, the incentive for mechanization is due to labor shortages. In addition, mechanization can provide cost and quality advantages to the grower, through more timely harvesting of the crop.

Robot farming is a term used to describe the performance of repetitive farming operations without the aid of an on-site human controller. Agricultural applications for robots will include mobile applications (combines, tractors, fruit and vegetable harvesters) and fixed applications (fruit and vegetable processing, feed handling, animal processing). Because of the variability of agricultural products and agricultural production environments, the successful application of robotics to agriculture will depend upon the development of hardware and software that can adjust to variable processes or products. Advanced control systems, possibly using artificial intelligence, will be needed for most robotic applications.

Current State-Of-The-Art

Mechanized Fruit and Vegetable Operations

As previously stated, the most significant opportunities for increased mechanization and reduced labor requirements in agriculture is associated with horticultural crops. Labor hours associated with the production of vegetables, fruits, and nuts, accounted for over 19 percent of total farm work hours in 1981 (Table 1). However, these horticultural crops accounted for only about 11 percent of the total value of all U.S. crop and livestock production in 1981. An average of 120 on-farm man-hours/acre of labor were required to produce, harvest, and handle U.S. horticultural crops in 1978 compared to approximately 3-4 man-hours per acre for grain crops such as wheat, corn and soybeans.

The amount of labor needed for hand harvesting horticultural crops is frequently 50 percent of the total labor required for a specific crop (ASAE, 1983). The high labor requirements for hand harvesting and the costs associated with these requirement have presented an incentive for replacing labor with mechanized systems. Researchers and growers have strived to develop equipment and methods for increasing the productivity of harvesting labor. Approaches have included changing cultivars, cultural practices, applying good human relations, rearranging the work pattern, developing labor-aid equipment and developing labor-replacement equipment. Labor-aid equipment (e.g., conveyors, platforms, and hoists) has been used for several fresh market vegetable crops, but has not proven successful in fruit crops. In some instances, difficulty in obtaining hand labor is causing a stagnation or decrease in crop acreage, an increase in cost to consumers, and an increase in imports of certain commodities (ASAE, 1983). Successful adoption of mechanical harvesting for a specific commodity is dependent on many factors. Since unique differences occur in climate, soil, terrain, labor, crop mix, markets, utilization, variety or plant type, a given level of mechanical harvesting technology may be adoptable in one production area, but not in another.

Producers of horticultural crops generally use hand labor when available at a reasonable cost. The adoption of mechanical harvesting usually occurs when hand labor is likely to be unavailable or appreciable savings will result from mechanization. The disadvantages of mechanization include the large capital investment requirements and the reduction in growers' flexibility to change from one crop to another or from one market (e.g., production for fresh versus process market) to another. When an adequate supply of hand labor is available the adoption of mechanical harvesting technology requires a very specific economic analysis. Part of this economic analysis recognizes that gross crop value per acre harvested can decline if a crop is easily damaged, is for the fresh market, or does not mature uniformly. The analysis also recognizes that mechanical harvesting can often recover more value per acre than can hand harvesting due to more timely harvest, especially when weather conditions accelerate maturity, or destroy unharvested crops. Quality, as well as quantity, of the harvested crop is the key element of economic feasibility.

Vegetable Crops. Vegetable crop harvesting is not intensively mechanized for a variety of reasons. Many vegetables for the fresh market are too delicate to be handled by any of the mechanical means devised to-date. Many vegetables do not ripen at the same time thus making selective harvesting a necessity. Mechanization often requires a large capital investment and can reduce the growers flexibility to change from one market to another. Also, most vegetables are grown on relatively small acreages; thus there is less incentive for a manufacturer to develop a harvester for such a small market (ASAE, 1983).

The harvesting of several process vegetables has been mechanized to some extent. This is possible since the effects of mechanical handling are not so noticeable on process vegetables. Process tomatoes, sweet and Irish potatoes, brocolli, cucumbers, lima beans, snap beans, sweet corn, green and southern peas, pumpkin and squash, beet, carrot, peppers, horseradish, garlic, dry onions, radish, turnips, asparagus, cabbage, celery, and rhubarb can be harvested commercially with mechanized pickers. Other crops for processing, such as cauliflower, lettuce, okra, and asparagus, have mechanical harvesting research underway.

The largest vegetable in terms of value of production is potatoes. Potatoes have been mechanically harvested for many years. The harvester undercuts and lifts the potatoes, shakes off loose soil and sorts out undersize potatoes. The potatoes are then transferred to bulk storage containers such as wagons or trucks. Some harvesters can pick six rows of potatoes at 2-4 miles/hr. Potatoes are easily damaged by bruising when mechanically harvested. As much as 20 percent of the potential value of the crop can be lost by bruising during harvest.

The second largest vegetable in terms of production value is tomatoes. The development of mechanical harvesters for tomatoes in the early 1960s was possible after the plant was bred to provide a suitable cultivar for machine harvest. The concurrent development of a mechanical tomato harvester and high-yielding machine harvestable tomato varieties gave California a production increase of 300 percent on only 50 percent more land. A more recent addition to tomato harvesters is the ability to mechanically sort tomatoes by color. Color sorting capability can reduce the labor required for a single machine by 10 people.

Dry onions provide another example of mechanically harvested vegetables. The mechanical harvesting method for onions is nearly the same as the method used to harvest potatoes. The main difference is that for some varieties of onions, the tops are removed by mowing just before harvest. For other varieties, the tops are removed by hand.

Fruits. The largest category of fruit crops in the U.S. is citrus. About 80 percent of this crop is processed into concentrated or single strength juice. Because of the size of the market and the large percentage of the crop that is processed, oranges would seem to be an ideal crop for mechanization. However, the "bag and ladder" method of hand picking is currently used to harvest oranges throughout the U.S. Many mechanization methods have been investigated and found to be impractical under current economic conditions. These include man-positioning equipment and fruit contact removal devices. One method that is used commercially for mass removal of some cultivars is mechanical or oscillating-air tree shakers. This method often is used in conjunction with abscission chemicals.

The "Valencia" cultivar accounts for about 43 percent of the U.S. orange production and is one of the deterrents to successful orange harvest mechanization. The fruit detachment force of "Valencia" ranges from 16-31 lbs. compared to 3-12 lbs. for the early and midseason cultivars. In addition, since "Valencia" oranges in most production areas are harvested two to seven months after the bloom and set of the next season's crop, there is the risk of reducing subsequent yield with most mechanical harvesters.

The second largest fruit crop in terms of total value is grapes. Machinery for grape harvesting was developed in the 1960's and 1970's by all of the major grape producing countries. Juice, wine, and raisin grapes can be mechanically harvested. All table grapes are hand harvested.

Mechanical grape harvesters are self-propelled, straddle-type machines that remove the fruit using rod shakers, vertical spiked wheel shakers, vertical impact shakers, or rail shakers. The vines may be trained to grow on a certain type of trellis for the harvester. In some areas, the grapes are stemmed and crushed in the field by portable machines that receive the fruit directly from the harvester.

Many of the deciduous fruits including apples, apricots, sour cherries, sweet cherries, nectarines, peaches, pears, plums, and prunes can be harvested for processing or dehydration by a method known as shake-catch. Mechanical shakers shake the trunk or limbs of the tree and the fruit is caught in netting arranged around the tree. Catching surfaces can be designed to minimize damage due to bruising. All fresh market deciduous fruits are harvested by hand.

Robot Farming

Agricultural engineers have attempted to develop robotic tractors for many years. Several different systems have been studied. Among these are systems that follow buried wires, others that triangulate from low-power radio transmitters in different parts of the field and other systems that use optical or mechanical sensors to sense some characteristic of the field or crop. All of these systems have limitations that have prevented their widespread commercial use.

Currently, research is underway to develop robot apple harvesting machines at Michigan State University. This system uses ultrasonic sensors to detect the tree trunks and steer the vehicle around the tree. Other researchers are developing machines for use with controlled traffic agriculture that will use robotic principles. Japanese researchers have developed a variety of robotic applications including robot rice harvesters, a tomato harvesting robot, and a computer controlled gantry farming system.

Use of robots in harvesting citrus is another potential commercial agricultural application of robot technology. Martin-Marietta Aerospace Corp. has developed a concept for harvesting oranges with a robot that would use guided missile technology. Honeywell Inc. analyzed 43 different crops from the standpoint of potential candidates for automation and specifically for an intelligent robot device. From their analysis, they have focused on harvesting of tree fruit, specifically oranges.

In 1983 a robot system with its processing algorithms for harvesting oranges is likely to cost $600,000 and only harvest one orange every 30-60 seconds. This system may harvest only 120 oranges per hour, which is far below the rate of a hand picker who harvests 1600 oranges per hour for $5.

It is not inconceivable, according to Honeywell, that by 1990 a robot may be developed that would cost about $50,000 in 1983 dollars. Oranges may be picked at the rate of 1 orange every 2 seconds for a rate that would exceed that of the human picker--1800 oranges per hour. The robot could work 24 hours per day, to aid the critical/cost performance ratio. Under certain assumptions of labor and capital costs one 1990 robot could do the work of three and one-third human pickers earning $11,000 each, with an annual picking savings of over $37,000. Thus, the initial $50,000 investment in a robot could be paid off in two years. (Pejsa, 1983).

While the above assumptions and analysis are debatable, it is useful to define labor intensive tasks being performed in today's agriculture since these are the candidate tasks for the intelligent robot systems that will be maturing during the remainder of the 20th century.

Animal Agriculture. Robotics also may have potential applications to animal agriculture as indicated by Muehling (1984). However, indications are that the most significant future changes in animal agriculture will not be in reduced physical effort, but in improved techniques making the livestock farmer a better manager. Robotics could reduce labor in livestock production with possible applications including: (1) checking lambing, calving, and farrowing; (2) identifying estrus; (3) managing feeding and other routine activities; (4) determining pregancy with echo-analysis; (5) assisting in manure handling; (6) assisting in slaughter and the fabrication of carcasses, and (7) administering insecticides. Muehling indicated possible technologies for development include voice communication with a robot and possibly the equivalent of olfactory sensing by a robot.

A project currently under way at the University of Western Australia is an example of a practical application of robots to animal agriculture. The equipment being developed will restrain, manipulate, and position sheep for automatic shearing (ASAE, 1983). Another potential application of robots and animal agriculture is the automatic attachment of teat cups during milking (Ordolff, 1983). Approximately 10 seconds per cow is required to attach teat cups in conventional milking operation, representing about 16 percent of the total labor. Although most dairy farms are highly mechanized today, technical reasons caused by various shapes of udders, and also economic considerations, have prevented the development of equipment capable of handling this final step of milking mechanization.

Other electronic aids in livestock production may improve overall production efficiency without a substantial reduction in labor input. Some examples include (1) better disease detection and diagnosis, (2) detection of optimum breeding times (estrus), (3) automatic weighing of livestock and poultry to monitor weight gain, and (4) microprocessor controlled feeding systems for individualized animal feeding.

These variables represent cost factors that exert as important impact on livestock operators' net profit as on-farm labor costs. They might be classified as "management aids" to assist the operators in making critical decisions. The objective of mechanizing or automating portions of the management operation is to provide correct information in a timely and easily interpreted format for the operator's decision making process.

Field Crops. Totally robot controlled tractors or combines are not likely to be commercialized by the end of the 20th century. The relatively low dollar value per acre of grain crops hardly justifies the research and development investment when labor requirements for most field crops are already less than 10 percent of total production costs. Robotic tractors or combines must be able to correct certain malfunctions such as clogging of tillage equipments and harvesters, and to make on-the-go adjustments to improve the machinery operating efficiency. In addition, totally robotic mobile agricultural equipment must be able to detect mechanical breakdowns and notify an overseer/operator.

Major Breakthroughs Needed

Many aspects of labor replacement in the future are likely to involve some aspect of electronics technology. Whereas many mechanical innovations were originated on the farm, ideas for new concepts in equipment or process control are now coming from electronic innovaters as transplants from military or aerospace electronics, or as offshoots from other industries having electronics capabilities. The innovations generated from such non-traditional routes sometimes need to modified for a sound agricultural basis. The challenge is to establish a meaningful dialogue between the agricultural and electronic technologists to arrive at realistic concepts, objectives, and schedules.

Another aspect of applying electronics to agriculture involves the variability of agricultural environments (e.g., temperature, soils, humidity, terrain, animal movement, etc.) to which electronic equipment is subjected. In addition, agricultural products themselves are highly variable. Different densities, moisture contents, sizes and shapes can exist within a single crop or group of animals. Because of the large amount of variation in biological products, it is difficult to quantify the electrical or chemical properties that should be sensed. For these reaons, it is important that the electronic designer be fully aware of environmental stresses (moisture, vibration, dust, etc.) to be encountered for a particular application.

Cost of additional mechanization and/or electronics applications to agriculture are critical to their successful implementation. Many sophisticated electronic solutions available to NASA for the space program are far beyond the budget constraints of farmers or the R&D departments of most agricultural equipment manufacturers. The challenge is to develop electronic designs which will survive the hostile agricultural environment with cost and value within reach of the farmers' pocketbook.

Many different segments of agriculture are becoming involved in electronic applications within their special areas of interest. The need for standardization in electronics is an issue being addressed by the American Society of Agricultural Engineers. This Society strives to provide a more global coordination in the important area of agricultural electronics standardization.

With regard to more specific breakthroughs, the application of robotics to picking citrus requires better sensors. A vision system may be required to determine the three dimensional coordinates for each piece of fruit within the harvesting zone. Force and touch sensors may supply the input both for fruit acquisition and for detecting twigs and branches enroute to the fruit.

The algorithms to process sensor data and other inputs in a closed-loop control system are developing rapidly, although they are extremely complex. Vision algorithms will be developed, although fruit hidden behind leaves and other problems may prove troublesome. Vision systems are currently too slow for use in a real-time control system. Future developments increasing speed and power of vision processors are expected.

Timing to Commercialization

The pace of future advances in mechanized production of horticultural crops is difficult to predict. If appreciable advances are to be realized towards mechanizing the production of fresh-market and minor crops, multidisciplinary research and development involving plant geneticists, horticulturalists, agricultural engineers, and electronics specialists will be needed. The growers and short-line equipment manufacturers do not appear to possess the financial resources required to conduct such high-risk research. The traditional source of this research, the USDA and land grant schools, is moving away from "applied" research into areas that are more "basic". Until a way is found to fill the need for research in this area, very little progress will be made towards solving the problems.

The introduction of robot farming systems into agriculture will depend upon the pace of developments outside the agricultural industry. There is not enough economic inventive to develop specialized robotic equipment specifically for individual agricultural applications. General purpose robots developed primarily for manufacturing may be adapted to agricultural applications. The sensors and vision systems needed for most agricultural applications will probably be developed outside agriculture and modified as needed.

Institutional Arrangements

Decreasing emphasis is being placed on expenditure of public funds for mechanization research. The private sector has been, and is likely to continue to be, an effective source of new mechanical technology for agriculture. The critics of public research in mechanization have emphasized its displacing effect on labor. However, empirical evidence suggests that mechanization has been induced by long-term increases in the price of labor, or by lack of labor during critical times in a crop's growing or harvest cycle (Ruttan, 1982).

Mechanical harvesting equipment for horticultural crops is built primarily by small and short-line manufacturers. The annual U.S. production of each harvester type rarely exeeds a few hundred and, in most instances, amount to fewer than 100 units. These manufacturers do not have large R&D budgets and frequently rely on a combination of publicly supported research results, growers' inventiveness, and their own ideas to develop new and improved equipment. The low volume of production implies that many machines are almost custom built. Very few are built under production line conditions typical of U.S. manufacturing. Therefore, these manufacturers attempt to make the machines simple to construct and maintain, thus limiting costs. The small production volume does permit the addition of special features to the machines when necessary.

Research in electronic innovations that may influence the quantity and quality of labor required is being conducted primarily by private companies such as Martin Marietta, Honeywell, Dickey-john, and TRW, among many others. Research on labor saving devices also is conducted at universities and agricultural experiment stations. However, the role of agricultural engineering research at these institutions and the U.S. Department of Agriculture is (as previously indicated) shifting to more "basic" research compared to "applied" or "developmental" research.

Potential Primary Impacts

In general, the extent to which mechanical power machinery will substitute for labor in the future appears to be leveling off as indicated by relatively small changes in indices of mechanical power and machinery inputs (127 in 1981 compared to 126 in 1978) and farm labor (64 in 1981 compared to 67 in 1978). Also, there was a less than two percent change in average horsepower per tractor between 1980 and 1982, after a 16 percent increase in average tractor horsepower from 1975 to 1980. Puckett (1983) indicated that the on-farm labor required for the production of most agricultural products has been declining to the extent that it is not a major variable for cost control.

Although the 1980-82 trends may be partially a result of the agricultural recession, they also support a observation recently made by David Garst (Agri-Marketing, 1984) in which he indicated that today's cost of machinery influences farm profits far more than the cost of labor. Garst predicts a reversal of past trends in the future, with labor increasingly replacing machinery in the production inputs mix.

Due to the high costs of machines, it is possible to reduce the per hour costs of tractors, tillage tools, or combines by increasing their hours of use. A specific illustration offered by Garst cites a self-propelled combine costing about $100,000 with interest and depreciation costs of about $34,000 per year. This $34,000 is roughly twice the amount required to hire a year-around farm employee. Thus, if the employee can be used to double the acres harvested his employment gives the farmer a two-for-one return, (fixed costs of the combine are spread over twice the harvested acreage), if all labor costs were amortized over the harvest period. In addition, the employee is available year round, an extra bonus of free labor during the off-season.

Along with a possible increase in labor to more efficiently utilize large scale farm equipment, there is likely to be a change in the "quality" of labor. The United States is now entering the "electronic age" of agriculture in which various types of electronic systems involving sensors, actuators, and control devices are being implemented to monitor crop and livestock performance, machine performance, and the environment in which crop, livestock and machinery are operating. These electronic technologies are not necessarily labor saving in the absolute sense, but they may require a less highly trained operator to respond and make corrective changes in performance where necessary. Advances in electronic technologies will enable some of these changes to be made automatically. Properly designed "black box" applications will be easy to maintain with built in self-diagnostics and modulized replacement components. Skilled service support must be available. This means that dealers will require technicians trained to service the electronic components.

A number of specific implications exist for growers changing from hand harvesting to mechanical harvesting of fruits and/or vegetables. Tree and vine crops frequently must be repruned or retrained if mechanical harvesting is to be efficient. Tree or vine modification to optimize mechanical harvesting can increase the speed of harvesting, promote uniform maturity, improve recovery, and decrease damage to product and plants. Biotechnology, in the form of genetic modifications, may help with these problems. Sometimes an orchard or field layout can be changed by removing obstacles to machines, thereby providing long continuous runs. Vegetable crops usually must be precision planted and thinned. Weed control is an important requirement for mechanical harvest. Careful attention to varieties, planting dates, and crop fertilization also is necessary to obtain uniform and proper timing of maturity. The cost and impact of these changes are important factors affecting the economic feasibility of mechanical harvesting to replace hand labor (ASAE, 1983).

Bulk handling systems almost always are necessary with mechanical harvesting. Mechanical harvesters have higher harvest rates than individual hand pickers. The resulting greater product flow usually cannot be efficiently containerized in the customary manner used for hand picking. The bulk handling system used must be compatible with the quality requirements for a particular crop.

Technology trends in citrus production point to higher density plantings. Tree spacing less than 7.5 meters between rows and 5.5 meters in the row with the trees maintained at 5 meters or less in height may become common. If high fruit yields can be obtained by maintaining these tree heights there is good potential for development of over-the-row equipment for production and harvesting. Mechanical harvesting from existing trees causes unacceptable fruit injury. A new electronic fruit grading system developed by Sunkist growers may eventually enable mechanically damaged fruit to be efficiently and adequately identified in the packing houses and diverted to processing. This development might improve the economics of mechanically harvesting for the fresh market. Harvesting citrus for fresh market will probably continue to be done by the "bag and ladder" in the foreseeable future. The needs for increased picker productivity and reduced harvesting costs are creating a gradual change towards smaller trees planted at higher density that can be efficiently hand picked from the ground or short ladders. Such trees will also be adaptable to mechanical harvesting.

REFERENCES

(1) American Society of Agricultural Engineers, Status of Harvest Mechanization of Horticultural Crops, 1983.

(2) Barker, E., "Farming Technology in Transition", Enterprise, June 1983, pp 4-7.

(3) Bohman, C. E., "Can Electronics Make it on the Farm?", Agricultural Engineering, Vol. 64, No. 11, November, 1983, pp 4-6.

(4) Cargill, B. F., and Rossmiller, G. E. (eds.), Fruit and Vegetable Harvest Mechanization Manpower Implications, RMC Report No. 17 (Michigan State University, 1969).

(5) Cargill, B. F., and Rossmiller, G. E. (eds.), Fruit and Vegetable Harvest Mechanization Policy Implications, RMC Report No. 18 (Michigan State University, 1970).

(6) Council for Agricultural Science and Technology, Agricultural Mechanization: Physical and Societal Effects, and Implications for Policy Development, February, 1983.

(7) Friedland, W. H., and A. E. Barton, Manufacturing Green Gold--Capital, Labor, and Technology in the Lettuce Industry, (Cambridge: Cambridge University Press, 1981.

(8) Garst, D., "New Directions in Agriculture", Agri Marketing, 30, 31-34, January, 1984.

(9) Key, S.J. and Ford, D.L., Robotics and Intelligent Machines in Agriculture, Proceedings of 1st International Conference, American Society of Agricultural Engineers, 1983.

(10) Miller, T. A., G. E. Rodewald, R. G. McElroy, Economies of Size in U.S. Field Crop Farming, U.S. Department of Agriculture, Economics and Statistics Service, Agricultural Economic Report No. 472, July 1981.

(11) Muehling, A. J., "Ag Engineer Predicts Robots Will Improve Farm Efficiency", Feedstuffs, 7 and 47, January 23, 1984.

(12) Ordolff, D., "Investigations on a System for Automatic Teat Cup Attaching", Proceedings of the National Conference on Agricultural Electronics Applications, Volume II, American Society of Agricultural Engineers, 1984, p. 501.

(13) Pejsa, J. H., "Agricultural Robots and Economic Issues", Agricultural Engineering, Vol. 64, No. 11, November, 1983, pp 15-16.

(14) Puckett, H.B., "Expectations from Electronic Aids for Livestock Production", Proceedings of the National Conference on Agricultural Electronics Applications, Volume II, American Society of Agricultural Engineers, 1984, p. 435.

(15) Ruttan, V. W., "Changing Role of Public and Private Sectors in Agricultural Research", Science Vol. 216, April 2, 1982, pp 23-29.

(16) Security Pacific Bank, California Agriculture, 1982, p 27.

(17) Smith, L. W., and R. Coltrane, Agricultural Labor Needs in the 1980s, Economics and Statistics Service, ESS Staff Report No. AGESS810113, January, 1981.

(18) U.S. Department of Agriculture, Agricultural Statistics, 1982, pp 411, 433.

(19) U.S. Department of Agriculture Economic Research Service, Changes in Farm Production and Efficiency, Statistical Bulletin No. 561, Washington, D.C., 1976.

Background Paper No. 27

Engine and Fuels

Battelle Columbus Laboratories
Columbus, Ohio

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

ENGINE AND FUELS TECHNOLOGIES

Summary

The substitution of energy for human labor, in the form of fossil fuels has been a significant contributor to increased agricultural productivity in the United States. Gasoline, diesel fuel, and electricity comprise over 80 percent of all farm energy expenses. In addition, LP gas and natural gas are important fuels for grain drying and irrigation, respectively.

This paper discusses three major lines of research, including (1) adiabatic compression ignition (CI) (diesel) engines with turbocompounding, (2) electronic engine controls, and (3) alternative fuels and energy sources.

An adiabatic thermal process is one which occurs without the transfer of heat across the system boundary. Present research is directed toward eliminating engine cooling systems and insulating piston/cylinder/head/liner areas to achieve near adiabatic operation. Engine maintenance costs will be reduced by eliminating the cooling system. Higher combustion chamber temperatures should increase the thermal efficiency of the engines; however, the primary result will be to increase the temperature of the exhaust stream of the engine, which then can be tapped by a turbocompound unit

Electronic engine controls have been developed by the automotive industry for use on gasoline spark ignition (SI) engines. These controls have increased automobiles fuel efficiency while maintaining emission

standards. Electronic engine controls may be applied directly to agricultural SI engines, while some of the controls technology can be applied to diesel CI farm engines.

During the 1970s, rapid escalation in fuel prices created interest in developing liquid fuels, such as ethanol, methanol, and vegetable oils, that could produced from farm products or from lignocellulosic materials such as municipal solid waste, woody biomass, and crop residues. Several ethanol plants are now operating which utilize corn as the feedstock. The ethanol is blended with gasoline to increase its octane rating. There also are a number of methanol blends with gasoline in limited commercial use today. Other alternative fuels concepts include low temperature drying of grain, use of solar energy to dry grain, and use of livestock wastes or as a feedstock for producing biogas.

The efficiency and reliability of turbocompounding relative to turbocharging needs to be demonstrated. Other adiabatic engine problems requiring additional research include high temperature lubrication, materials strength, and durability.

Improved tractor electronic instrumentation and systems monitoring will aid in better chemical and fertilizer application. Fuel efficiencies on tractors should be increased from 5-15 percent over the next 10-15 years. Also, engines should be more durable, with a longer life and lower repair costs.

Farmers will be purchasing increasingly sophisticated tractors and farm machinery that will perform more functions automatically and be more fuel efficient, therefore enabling the farmer to do a better job of soil tillage, planting, or harvesting. The biggest uncertainty centers around the cost/reliability of these improvements relative to the benefits of increased productivity and operator comfort. Meeting the demand for component service on electronic systems will be a challenge to the farm equipment industry over the next decade.

The use of alternative fuels such as ethanol, methanol, and vegetable oils requires additional research for commercialization in a number of areas. Opportunities for process improvements in manufacturing ethanol include developing economically effective methods of pretreating and hydrolysing cellulosic materials, such as crop residues, and developing practical organisms for converting five carbon sugars to ethanol. The effects of various fats and oils on the durability and performance of diesel engines need to be investigated. Methanol is inexpensive and currently this industry has excess capacity. Water sensitivity of gasoline-methanol blends is a problem, as are low temperature starting problems for most methanol fuels.

The current cost of vegetable oil, exceeding $2.00 per gallon, does not favor its substitution for diesel fuel selling for slightly over $1.00 per gallon at the farm level. Generally speaking, a leveling out in liquid fuel prices has slowed commercialization of all biomass derived fuels. Unless there is another sharp escalation in petroleum prices, the production of alcohol and vegetable oils for fuel should not exert a significant impact on the United States' agricultural economy for the remainder of the 1980's decade. Widespread adoption of grain crops and oilseeds as fuel feedstocks would rapidly escalate their prices, thus making them less competitive as fuel feedstocks. Such price increases would have major impacts on livestock production costs and the cost of grain-derived food products.

It is important to continue research on alternative fuels because of political uncertainties affecting the supply and price of imported petroleum. Also, there is a finite supply of fossil fuels that eventually will be exhausted. Renewable biomass, in the form of alternative crops, cropping systems or lignocellulosic materials, is an important component of a long-term alternative fuels program. Biomass production and processing systems that will not adversely affect United States food supplies/prices should be developed and demonstrated.

ENGINE AND FUELS TECHNOLOGIES

Introduction

One of the major reasons for farming's increased productivity during the twentieth century has been the replacement of human labor with power provided by fossil fueled engines. This paper will discuss some recent developments and implications of the changing technologies associated with engines and fuels.

Fuels, lubrication, and electricity account for approximately 2-8 percent of total cash expenses associated with livestock production, and about 10-15 percent of total cash expenses for field crops. Table 1 indicates farm energy purchases by type of energy in the United States for the year 1979. Together, gasoline, diesel fuel, and electricity comprised over 80 percent of all farm energy expenses, which amounted to $10.3 billion in 1979. LP gas and natural gas also are important fuels for grain drying and irrigation.

Table 2 indicates energy purchases by type of farm in 1979. The largest single category of energy expenses is accounted for by "other livestock" farms which include beef cattle and swine operations. These operations accounted for 35 percent of total farm energy purchases, but had the lowest average expenses per farm--slightly over $3500. Poultry operations had the highest energy expenses per unit of operation, which is not unusual given the extremely large scale of individual broiler and egg operations. Overall, energy expenses are roughly equal between crop and livestock operations.

TABLE 1. FARM ENERGY PURCHASES BY TYPE OF ENERGY, UNITED STATES, 1979.

Fuel Type	Units	Expenses (Million $)	% Of Total Farm Energy Expenses
Gasoline (Million Gallons)	4,322	3,817	37.1
Gasohol (Million Gallons)	36	36	0.3
Diesel Fuel (Million Gallons)	3,057	2,357	22.9
Fuel Oil (Million Gallons)	488	365	3.5
LP Gas (Million Gallons)	1,695	853	8.3
Natural Gas (Million Cu. Ft.)	122,569	276	2.7
Coal (Thousand Tons)	455	22	0.2
Electricity (Million KWH)	50,029	2,152	20.9
Kerosene	N.A.	23	0.2
Motor Oil and Grease	N.A.	355	3.4
Other -- Wood, Coke, Etc.	N.A.	49	0.5
TOTAL	N.A.	10,305	100.0

Source: U.S. Department of Commerce, Bureau of the Census, 1979 Farm Energy Survey, Volume 5, Special Reports, Part 9.

TABLE 2. ENERGY PURCHASES BY TYPE OF FARM, 1979.

Type of Farm	Number Farms	Total Energy Expenses	% Of Total	Average Expenses Per Farm
	(000)	($ 000,000)	(%)	($)
Cash Grain	524.9	3,099	30.1	5,903
Fruit, Nut, or Vegetable	111.7	581	5.6	5,201
Other Crop	348.4	1,697	16.5	4,871
Dairy	167.4	998	9.7	5,962
Poultry	49.5	320	3.1	6,464
Other Livestock (primarily beef and swine)	1,013.1	3,611	35.0	3,564
Total, All Farms	2,215.0	10,306	100.0	4,652

Source: U.S. Department of Commerce, Bureau of the Census, 1979 Farm Energy Survey, Volume 5, Special Reports, Part 9.

The primary power for mobile agricultural equipment during the next twenty years will be provided by diesel, compression ignition (CI) engines. Several vehicles on the farm, such as cars, trucks, and small tractors will continue to use gasoline, spark ignition (SI) engines. For most applications where a large amount of continuous portable power is required, CI engines will be used because of their inherently higher efficiency.

Since CI engines will be used to provide most of the portable power used on farms, the majority of research being done on engines and fuels for agricultural applications is directed toward increasing CI engine efficiency. Some of the research on engine and fuels is being done for the transport industry. Manufacturers of engines for off-highway use also are pursuing such research in many countries of the world. This work is expected to have significant impacts on engines used in agricultural applications, particularly the CI engines used in agriculture.

This paper will discuss three major lines of research. These major lines of research are:

- Adiabatic CI engines with turbocompounding
- Electronic engine controls
- Alternative fuels and energy sources.

Adiabetic CI Engines with Turbocompounding

An adiabatic thermal process is one which occurs without the transfer of heat across the system boundary. Present military and transport industry research is being directed toward eliminating engine cooling systems and insulating piston/cylinder/head/liner areas to achieve near adiabatic operation. The elimination of the cooling system will reduce engine maintenance costs. Higher combustion chamber temperatures will increase the thermal efficiency of the engines; however, the primary result will be to increase exhaust stream energy by capturing energy normally lost to the cooling system. The increased exhaust stream energy then is tapped by a tubocompounding unit. The turbocompounding unit uses the exhaust gas to spin a small turbine in the exhaust stream. This recovered power is applied directly to the driveline through gearing. The adiabatic or near adiabatic turbocompound CI engine therefore is more efficient than the normal CI engine. Turbocompounding also may be used on standard (non-adiabatic) CI engines to recover part of the normally lost energy.

Electronic Engines Controls

Electronic engine controls have been developed by the automotive industry for use on spark ignition (SI) engines. These controls have enabled the manufacturers to increase the fuel efficiency of automobiles while maintaining strict standards for emissions. Electronic engine controls may be applied directly to SI engines used in agriculture, while some of the controls technology can be applied to CI farm engines.

Alternative Fuels and Energy Sources

Petroleum based fuel price increases during the past decade, along with concerns about fuel availability, have caused increased interest in developing alternative liquid fuels that can be produced from renewable resources. The most likely alternative liquid fuels are (1) vegetable oils, (2) ethanol derived from grain, sugar crops, or lignocellulosic materials, or (3) methanol.

Current State-of-the-Art

Adiabatic CI Engines with Turbocharging

The turbocompound and adiabatic CI engine technology is being developed at Cummins Engine Co., in a cooperative program funded by the Department of Energy and TARADCOM. Dynamometer and vehicle tests have been made on conventional turbocharged diesel engines which have been compounded. Prototype adiabatic engines have been tested on a dynamometer and a demonstration in an Army truck is planned.

Significant power increases and fuel efficiency increases for the same power setting have been realized for turbocompounded engines. Fuel consumption improvements of 15 percent were demonstrated. The performance target for the next prototype turbocompound engine is a 20 percent improvement over a conventional CI engine. Turbocompounding adds a significant amount of complexity to the power unit. Some of this complexity can be avoided by using turbocharging as the means for recovering exhaust gas energy, however the efficiency is not as high as when the adiabatic engine is turbocompunded.

Some of the information learned in the research on adiabatic engines may be used commercially before fully adiabatic engines are available. Several engine manufacturers are investigating the use of ceramic or other material type inserts for portions of the engine. These inserts would be used in high temperature portions of the engine. Completely ceramic turbochargers are being produced today. The advantages would include: (1) lower heat loads to the cooling medium, (2) higher energy content in the exhaust gas for use with a turbocharger, (3) higher fuel efficiences from the higher engine operating temperature, and (4) possible increased engine durability.

Electronic Engine Controls

Several manufacturers are developing electronic engine controls for CI engines. Electronic control of fuel injection metering for diesel engines is being developed to provide faster response to load changes and to reduce fuel waste. In 1981, Komatsu developed an electronically controlled high pressure injection system for heavy duty diesel engines. This system is able to control the engine speed to within 2 RPM, the timing of injection to 0.5 degree of crank angle, and the accuracy of fuel delivery to ± 0.1 percent of maximum fuel. Ford Motor Co. worked on an electronic diesel fuel control which could reduce diesel particulate emission by 37 percent over the baseline mechanical governor on light duty diesels. American Bosch has released for production a fuel injection pump which can use either standard mechanical controls, or can be used for better control on pump mounted, fuel cooled, microprocessor based control systems.

These controls will be used to reduce emissions and increase fuel economy as is currently done with engine control systems for automobiles. Agricultural tractors also will use information on soil and traction conditions, pulled implement demands, and operator inputs to optimize the operation of the vehicle for varying conditions. Automatic electronic control of gear shifting is likely in order to keep engines operating in their most fuel efficient speed range at all times during field operation, and to "do more work" with smaller, more efficient engines. The ultimate in efficiency is viewed as a continuously variable transmission (CVT) with infinite speed ratio variability coupled with load sensing and automatic control to maintain optimum engine efficiency, speed, and load. Currently available 15-speed powerlift transmissions are adaptable to electronic controls.

Developments in automobile engines sensor technology may eventually be transferred to tractors and combines. State-of-the-art sensors have been applied or recently developed for over-the-road vehicles These include a variety of torque sensors, and several types of sensors for determining air-fuel ratios. Various methods for measuring automotive torque are available, although none is totally satisfactory. Magnetic based torque sensors overcome many of the objections to more precise measuring techniques and have the desirable features of contactless measurement, rapid response, stability, good accuracy, ruggedness, high sensitivity, and high overload capacity. These features also are desirable in farm tractors. Other devices permit measurements of cylinder pressures, mass air flow, and crank shaft position, though extensive work remains to be done before many such systems will be practical.

Microprocessor based systems can use inputs from sensors and the operator to calculate and display information to control tractor and engine performance to achieve best system efficiency. This information can include:

- Area per hour rate
- Accumulated area
- Ground speed--true ground speed with available ground speed sensor
- Wheel slip with available ground speed sensor
- Programmable elapsed time indicator.

Some systems allow integrating a number of input signals thereby providing "intelligent conditional warning". For example, engine oil pressure is compared to RPM, and the status of both inputs determines the alarm condition. Filter restriction indicators have on/off switching status compared to time, and audible alarms are delayed to eliminate annoying false or repetitive diagnostic messages. Tractor speed of 0.5 MPH is required to trigger a handbrake "on" warning. Numerous combinations of temperature, pressure, level, and RPM can be compared to each other or to a timebase or database and provide a true, multi-parameter condition statement (Mueller and Knepler, 1983).

Improved system reliability is a major design goal in new dashboard information systems. The accuracy and reliability of the vehicle sensors, wiring, and actuators are extremely important, since component failure can result in false information and incorrect action. Such problems must be minimized for the tractor operator to have confidence in the monitoring system and to avoid unnecessary down-time.

Work is underway to develop direct voice communication with computers that will allow airline and military pilots to monitor a particular function while also being able to obtain other information by asking the computer for it. These systems may be adapted to agricultural applications.

Existing systems exhibit 90-98 percent accuracy in recognizing commands from the individuals who "trained" the system. While all present systems have limited vocabularies, voice interface technology has improved rapidly over the past decade. Special purpose integrated circuits now are becoming available, resulting in reduced size, weight, and costs. No single technique has emerged which is best for all purposes. Developers must consider trade-offs with respect to various attributes such as component costs, implementation complexity, and user acceptability.

Alternative Fuels and Energy Sources

The U.S. Department of Energy has assigned the lead role for directing the National Program of Alcohol Fuels to the Solar Energy Research Institute (SERI). The overall objectives of the program are (1) to develop the conversion technologies for transforming lignocellulosic biomass into fuel alcohols, and (2) to provide a mechanism for the early transfer of mature processes to the private sector. SERI's program consists of a mixture of in-house research activities and sub-contracted research (Douglas, 1984).

Figure 1 shows the general conversion pathways for producing alcohols from biomass. SERI's alcohol fuel program is conducting or funding research only in pathways 3 and 4. The starch and sugar bioconversion processes (pathways 1 and 2) are considered commercially proven and therefore require no federally funded research and development support. Research on pathway 5 is being conducted at SERI by Biomass Program researchers (Douglas, 1984).

Ethanol Production. The primary objective of SERI's ethanol research is to develop the research data to improve the cost effectiveness of ethanol production processes. Research activities concentrate on the operations that appear to offer the best opportunities to reduce the cost of producing ethanol. Specific research areas include (Douglas, 1984):

- acid hydrolysis processes
- enzymatic hydrolysis processes
- genetic engineering
- pretreatment research
- separations research
- by-product research
- parametric and sensitivity analysis.

Ethanol is widely used today in the U.S. in blends with gasoline (up to 10 percent ethanol, 90 percent gasoline) as an octane enhancer. In Brazil, pure ethanol has been used for a number of years in place of gasoline for automobiles. Tractors burning pure ethanol are also under development in Brazil by some of the same companies operating in the United States.

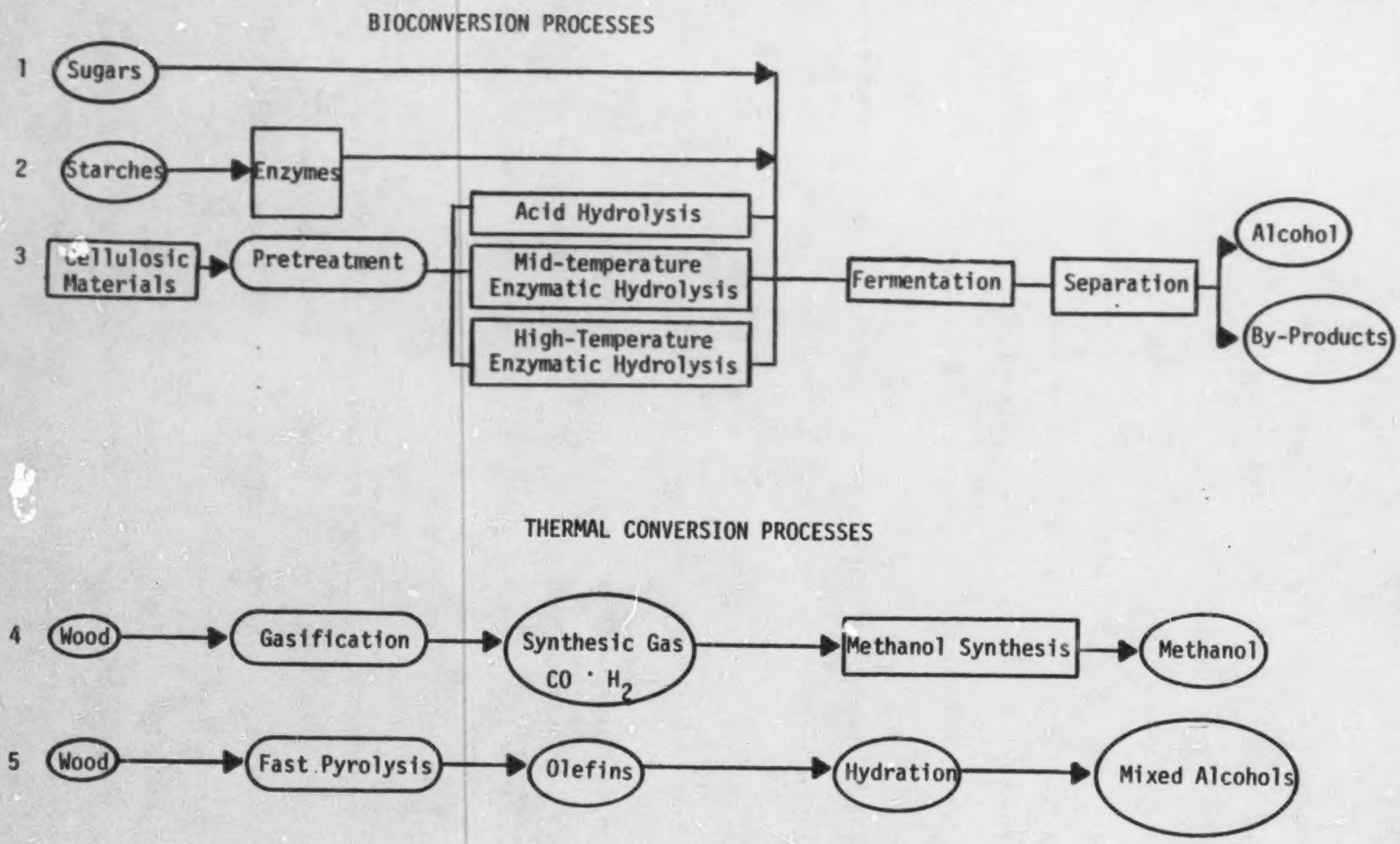

BIOCONVERSION PROCESSES
1
Sugars
2
Starches
Enzymes
3
Cellulosic Materials
Pretreatment
Acid Hydrolysis
Mid-temperature Enzymatic Hydrolysis
High-Temperature Enzymatic Hydrolysis
Fermentation
Separation
Alcohol
By-Products
THERMAL CONVERSION PROCESSES
4
Wood
Gasification
Synthesic Gas CO · H2
Methanol Synthesis
Methanol
5
Wood
Fast Pyrolysis
Olefins
Hydration
Mixed Alcohols

FIGURE 1. CONVERSION PATHWAYS FOR PRODUCING ALCOHOLS FROM BIOMASS.

Source: Douglas, L.J., "Perspectives on the SERI Alcohol Fuels Program", proceedings of the 19th Intersociety Energy Conversion Engineering Conference, August, 1984, Volume 2, pp. 692.

Ethanol/diesel fuel blends have been tested in CI (diesel) engines. Blends with a high percentage of ethanol do not work well in CI engines becuase of the low cetane rating of the ethanol. Also, there are problems with the ethanol separating from the diesel fuel in the tank.

Cellulosic materials for potential production of ethanol and methanol are found in municipal solid wastes, woody biomass, and crop residues; all of these are potential feedstocks for bioconversion and thermal conversion processes.

Methanol Production. SERI's methanol production element consists of three areas of research activity: (1) gasification research, (2) synthesis and catalysis, and; (3) methanol fuel cells. Gasification research is directed at developing the down-draft, fixed-bed oxygen gasifier. This design offers the advantage of simplicity of operation and production of a relatively clean synthesis gas for methanol production. Synthesis and catalysis research is directed at developing a homogenous bimetallic catalyst for converting syngas into methanol and other low molecular-weight alcohols. The goal of this research is to catalyze with high selectivity, which requires lower temperatures and pressures for operation than conventional heterogeneous catalysts. Fuel cell research studies use methanol as a fuel through an in-situ membrane bound catalyst to convert the methanol to hydrogen and carbon dioxide (Douglas, 1984).

In comparing methanol versus gasoline as a fuel, the critical differences are methanol's higher heat of vaporization and lower heat of combustion. These two big differences lead to the significant improvements of methanol in spark ignition engines--lower flame temperatures greatly drop NO_x emissions, combustion near to stoichiometric, and higher power and thermal efficiency (Galloway and Patterson, 1984).

Evaporate emissions for gasoline-methanol blends containing less than 10 percent methanol are significantly worse (i.e., 200 percent) than with straight gasoline owing to methanol's effect on increasing hydrocarbon volatility. However, the addition of higher boiling alcohols help reduce this evaporative emission problem as measured by a lower increase in the Reid vapor pressure (RVP). There are a number of methanol blends that are used commercially in the United States today. Many use methyl tertiary butyl ether to control the RVP. ARCO has the largest market with nearly 10 million gallons of unleaded regular gasoline containing "oxinol" (5.5-9.5 percent methanol and tertiary butyl alcohol) sold through 100 service gallons (Galloway and Patterson, 1984).

Some consideration also recently has been given to increased use of methanol in place of diesel fuel, which is the primary fuel used in motorized farm equipment. Formally it was thought that methanol would not be successful in diesel engines owing to its 870F autoignition temperature being so much higher than 600F diesel fuel. California tests demonstrated that a Golden Gate Transit, methanol-fueled bus powered with a conventional Detroit Diesel Allison (6V92) turbo-charged compression ignition engine could perform. A second bus demonstration is now underway that will use a German MANN vehicle. The fuel being used in both cases is nearly pure methanol with very small quantities of amyl-nitrate added for lubricity (Galloway and Patterson, 1984).

Vegetable Oils. Vegetable oils have been demonstrated as suitable for short term replacement for diesel fuel in CI engines in an emergency. However, vegetable oil prices are currently too high to justify prolonged use as fuel. In addition, the prolonged use of vegetable oils in direct injection of CI engines can lead to serious combustion chamber and lubrication oil problems.

Crop Drying. In the major corn producing states of Illinois, Iowa, Nebraska, an estimated 15-25 percent of the corn is dried with low temperature or ambient air. Low temperature drying systems could double within the next decade. One disadvantage of low temperature drying systems is that they require greater use of monitoring and controlling techniques than high temperature drying methods. There is also greater risk of economic loss due to spoilage because the grain is held longer at high moisture levels.

The use of solar energy has contributed to reduced fossil fuel requirements for crop drying. Drying with solar heated air probably does not involve more than 2 percent of the crop in any state, but there is increasing interest in applying this technology. There could be an impact on drying equipment sales in the next few years.

Animal Wastes. Anaerobic digestion of animal manure to produce biogas (a mixture of approximatley 40 percent CO_2 and 60 percent methane plus small quantities of other compounds, such as hydrogen sulfide) is practiced in some large livestock operations. The biogas is collected and used to fuel an internal combustion engine that drives an electric generator. The electricity can be used on-site or sold to an electric utility.

In a common digester system, the manure is stored in a settling pond prior to digestion. The manure is fed into a long tank digester, where it remains for several weeks. The digested manure exits the other end of the digester tank to be stored in an effluent lagoon. Further exploitation of the manure resource requires digester designs for relatively small operations, with low installation costs and automatic operations. However, such applications may have greater attraction in countries outside the United States.

Major Breakthroughs Needed

Before adiabatic and turbocompound engines are adopted commercially, several major technical and economic breakthroughs will be needed. The advantages of turbocompounding versus turbocharging for fuel efficiency will have to offset the potentially lower reliability and higher costs of the turbocompound system. Turbocompounding will have to demonstrate superior efficiency since turbocharging is a mature technology that has been proven to be efficient, reliable, and cost effective.

The breakthroughs needed for the adiabiatic engine are related to the problems caused by the high temperatures inside the engine. Material strength, lubrication, and durability at high temperatures are all problems that must be solved before full or partial adiabatic engines are adopted commercially. Ceramic materials may be used for high temperature sections of the engine. However, ceramics must be developed that will have sufficient material strength and durability to meet current durability needs. Even if materials are developed that can operate at the temperatures of an adiabatic engine, there are no good lubricants currently available to lubricate the moving parts. This decreases the efficiency gains because more energy is wasted overcoming resistance. Durability is decreased because the lack of lubrication increases wear.

The lack of sufficiently accurate, reliable, and low cost sensors is a problem limiting development of new electronic control systems for improving tractor and combine productivity. Low cost servo valves, actuators and improved connectors also are needed for agricultural applications. Differences in use criteria and costs prevent easy transfer of recent hardware developments to agriculture from other industries.

Voice interface technologies will be adopted after very accurate, low cost systems are developed for other industries, most notably automotive manufacturing. Breakthroughs are needed to allow systems to recognize large vocabularies from any voice with very little or no training. Artifical intelligence breakthroughs are needed so that voice interface systems can recognize speech in context or interpret the meaning of commands given in different ways.

Engine lubricating oil contamination is a hindrance to the use of vegetable oils in CI engines. Tests involving use of vegetable oils in CI engines have resulted in incomplete combustion and increased chemical reactivity of some engine oils at elevated temperatures. Engine lubricating oils need to be developed that are more tolerant of the special problems associated with the use of vegetable oils in CI engines. The development of economic processes for converting vegetable oils to methyl or ethyl esters would make vegetable oils a more desirable alternative fuel.

The technology for making ethanol from corn and sugar crops is well established. However, large amounts of these materials would be needed to significantly affect total U.S. fuel requirements. For example, 20-25 percent of the average U.S. corn crop would be required to produce sufficient ethanol to replace the gasoline used on U.S. farms. Currently, fuel ethanol is used primarily in blends with gasoline to improve its octane rating and improve performance of SI engines. In producing fermentation alcohol, opportunities for process improvements include the following (Keim, 1983):

- Economically pretreating and hydrolysing cellulosics (see previous discussion of SERI's research program),

- Developing practical organisms for converting five carbon sugars to ethanol and,

- Using bacteria or immobilized yeast for higher fermentation yields and proven efficiencies.

Water sensitivity of gasoline-methanol blends is a problem, which is partly solved by higher boiling alcohol addition; a mixture of 5 percent tertiary butyl alcohol, 15 percent methanol, and 80 percent gasoline tolerated 4,000 PPM water at 70F, where as a 15 percent methanol, 85 percent gasoline blend tolerates only 1,500 PPM water.

On the other hand, neat methanol fuels have an opposite volatility problem. Low temperature starting problems must be corrected by the addition of volatility improvers. For example, in an ongoing test in California some 1,000 methanol vehicles are being tested with a methanol fuel consisting of 90 percent methanol and 10 percent unleaded gasoline (Galloway and Patterson, 1984).

In the United States, methanol production capacity is considerably overbuilt. Older, high pressure nickel-chrome catalyst plants have been forced to close over the last decade to be replaced by larger (greater than 600 tons per day) low pressure copper catalyst plants. Inexpensive methanol is available but a challenge is to make use of this excess production for the transportation industry, as well as the farm sector which uses predominately diesel fuels.

Presently there is little economic incentive to utilize vegetable oils as replacement for diesel fuel with vegetable oils selling in the range of $2.00-2.50 per gallon compared to diesel fuel prices of approximately $1.00 per gallon for on-farm delivery. However, political and economic considerations in the major oil producing countries could, at some point in the future, result in sharply higher petroleum prices and greater incentives to use vegetable oil to fuel farm equipment in order to maintain U.S. food production.

A research program to develop vegetable oils for fuel uses has many facets, from potential changes in cropping practices all the way through to modifications in diesel engines to accomodate vegetable oils, as indicated in Figure 2. Key issues involved in developing vegetable oils as diesel fuels revolve around:

- Effects of various fats and oils on the durability and performance of diesel engines
- Evaluation of various purity levels that are associated with different degrees of oilseed processing and refining
- Investigating the feasibility of small local processing units compared to the present large scale units
- Investigating the feasibility of oilseed processing/conversion units specialized for the use of a predetermined oilseed compared to a general processing facility using the currently cheapest raw material.

Other alternative energy forms are being considered. One example is using biomass, such as sweet sorghum, to generate electricity. Problems that need to be addressed in this type of venture include:

- Uncertain weather effects on crop yields, which present year-to-year fluctuations in biomass

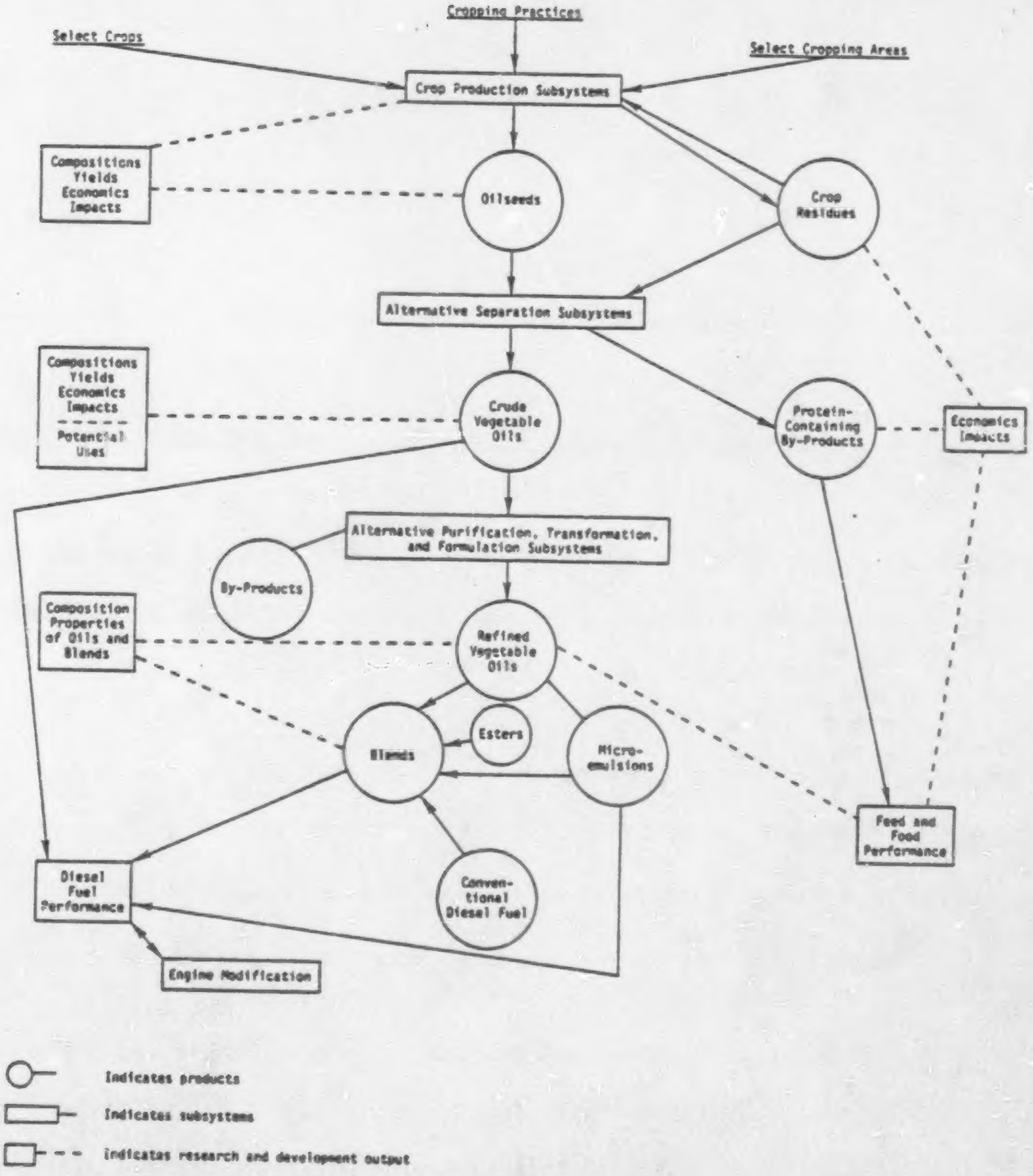

Cropping Practices
Select Crops
Select Cropping Areas
Crop Production Subsystems
Compositions
Yields
Economics
Impacts
Oilseeds
Crop
Residues
Alternative Separation Subsystems
Compositions
Yields
Economics
Impacts
Potential
Uses
Crude
Vegetable
Oils
Protein-
Containing
By-Products
Economics
Impacts
Alternative Purification, Transformation,
and Formulation Subsystems
By-Products
Composition
Properties
of Oils and
Blends
Refined
Vegetable
Oils
Esters
Blends
Micro-
emulsions
Feed and
Food
Performance
Diesel
Fuel
Performance
Conven-
tional
Diesel Fuel
Engine Modification
Indicates products
Indicates subsystems
Indicates research and development output

FIGURE 2. PROGRAM FOR DEVELOPING VEGETABLE OILS AS DIESEL FUEL SUBSTITUTES.

Source: Battelle Columbus Division, Systems Study of Animal Fats and Vegetable Oils for Use as Substitute and Emergency Diesel Fuels, report to the U.S. Department of Energy; October 30, 1981.

production. The variability in annual production means that the biomass combustion facility may have excess or insufficient capacity, which impacts its annual operating costs.

- The potassium content of biomass coats the heat exchangers and reduces the heat efficiency of the boilers.

- The moisture content of biomass affects its storage and transportation costs. Economical biomass transportation requires drying and densifying the material. However, these costs may more than offset lower costs offered by the raw material itself. In general, more efficient storage, handling, and transportation systems for cellulosic crop materials need to be developed.

Institutional Arrangements

Research in engines and fuels is conducted by industrial firms associated with transportation and agriculture, private research institutes, universities, and federal (DOE/Solar Energy Research Institute) and state government agencies. Research to improve general engine efficiency and performance is conducted by companies such as Cummins, Perkins (Division of Massey Ferguson), Deere and Co. , Allis Chalmers, International Harvester, J. I. Case, Ford Tractor, and Caterpillar Company Tractor Co. among others.

Tractor engine/fuel related research also is conducted by various agricultural and mechanical engineering departments at universities some examples include University of Illinois, University of Wisconsin, North Dakota State University, the University of Idaho, Kansas State University, and the University of Nebraska.

Southwest Research Institute has done considerable research in utilization of vegetable oils, methanol and ethanol as replacement for diesel fuel. Battelle Columbus Division, Oakridge National Laboratories, The Gas Research Institute, and the Electric Power Research Institute all have conducted numerous biomass/energy investigations, as have universities such as Texas A&M, Purdue, and the University of Florida, among others.

Likely Timing to Commercialization

Fully adiabatic engines probably will not be available before the early 1990's or later. Several problems concerning high temperature lubrication, material strength, and durability must be solved to make commercialization of this technology a success. Turbocompounded engines are likely to be commercially available much sooner since most of the major problems of current prototypes can be solved without major breakthroughs in lubrication and materials.

Electronic engine controls have been used for many years on SI engines in the automotive industry. The expertise developed on automotive systems is now being transferred to CI engines for over-the-highway trucks and off-road vehicles. There will be significant use of electronic controls on CI engines within the next 5-10 years. In agriculture, a much more difficult problem is how to integrate electronic engine controls into a vehicle control system. The control system will include tractive efficiency control and will allow the operator to set vehicle operation for optimum fuel consumption or maximum power use. These systems will be developed over the next 10-15 years and will eventually incorporate automatic guidance.

Widespread commercialization of alternative fuels is highly dependent upon availability and price of conventional, petroleum-based fuels. Technically, it is feasible today to operate engines using ethanol, methanol, or vegetable oils. Ethanol already is widely used as an octane enhancer and to improve engine performance. Also, the use of low temperature grain drying systems is being practiced today and could double within the next decade. Assuming no change from 1984 petroleum supply/demand balances and with no additional government subsidies, widespread commercialization of methanol, vegetable oil or other alternative fuels is not anticipated in the foreseeable future. On the other hand, if changes in world political events (i.e., a major war) create fuel shortages or a sudden upward shift in crude oil prices, there would be renewed interest in utilizing various alternative fuels. In this event, government subsidies or other appropriate incentives might be considered. Gearing up production to meet potential fuel demand could take some time. For example, methanol plants are large scale, high capital investments, and it is unlikely that any methanol plant would be on stream until at least 3-4 years after such an event would occur.

In general, conservation and technology development efforts by American companies and consumers have helped to alleviate the "fuel crisis" of the late 1970's. These efforts, in conjunction with assumed adequate petroleum supplies, should postpone any major shift away from petroleum based fuels for use in engines over the next decade.

Potential Primary Impacts

Engine and Electronics

Sophisticated tractor electronic instrumentation and systems monitoring offer crop farmers potential savings. For example, it is important to accurately monitor and display true ground speed for chemical and fertilizer application. Field studies have shown that poorly monitored application procedures can result in losses as high as $50.00 per acre. Wasted chemicals and actual crop loss can be caused by over-application of herbicides and fertilizers. Under-application is ineffective and wastes labor and machine time. With true ground speed monitoring capability, an average savings of $5.00 per acre per application is not unrealistic. As pesticide materials increase in price, the cost effectiveness of this system will continue to grow. Calculation and display of slip conditions during heavy tillage operations is acknowledged as a valuable tool to maximize performance and reduce tire and machine wear, thus offering further cost savings (Mueller and Knepler, 1983.

Opportunities exist to increase tractor fuel efficiency, with estimates ranging from 5-15 percent over the next 15 years. Tractor engineers feel that modifying tractor operating techniques will be as important as engine design modifications for increased fuel efficiency.

Astute farmers are considering fuel economy as part of an overall management strategy, in which they look beyond the fuel efficiency of an engine or tractor to total on farm energy use in terms of gallons per bushel, per acre, or ton of crop produced. For example, in 1982 fuels and lubrication costs for corn in the United States were estimated at about $20 per acre, or about 10 percent of total cash production expenses. Assuming no change in fuel prices, a 15 percent increase in fuel efficiency would reduce fuel costs by approximately $3 per acre for corn, or by about 2.5 cents per bushel, assuming a 120-bushel per acre crop yield.

Engines should be more durable and have a longer life, with possibly lower repair costs. This could result in operators keeping their tractors for a longer period of time. Engine life, however, would still be highly dependent upon the individual operator's attention to routine maintenance. At this point it is speculative as to whether the benefits of improved engine durability will be factored into higher engine prices. However, most ceramic components being considered for use in engines are more expensive than steel components.

Perhaps one of the greatest impacts of the increasingly sophisticated electronic systems being installed in today's farm machinery will be on the dealer technician servicing the machinery. Up to 1983, most electronic devices have been for warning or monitoring purposes. These devices have experienced failures, which result in incorrect diagnosis of engine or machinery malfunctions. Studies by John Deere have shown a high rate of wrong diagnosis; replacement of non-failed components has run any-where from 20 to 60 percent, and as high as 80 percent in certain cases. This results in customers paying for excessive and unnecessary repair costs and also may result in extended down-time. When this occurs under warranty, the manufacturer generally bears the excess direct cost (Conrads, 1983).

In general, meeting the demand for competent service on electronic systems will be a challenge to the farm equipment industry. To meet the challenge, self-diagnostic features are now being incorporated into electronic modules. When self-diagnostic features are not used, technicians have to acquire a high level of diagnostic ability, and must learn to follow step-by-step procedures. Technology in the form of "expert systems" computers, video disc manuals, and sophisticated diagnostic systems will help; however, training and retraining must be done with greater frequency. Service technicians will need to spend more time in service schools. Currently technicians may receive about five days of formal training each year, in the future, dealers must eventually plan to have their technicians in training for about two weeks per year (Conrads, 1983).

Overall, United States' farmers will be purchasing increasingly sophisticated farm machinery that will do certain functions automatically that now must be done manually, will be more fuel efficient, and should enable him to do a better job of soil tillage, planting or harvesting. The biggest uncertainty revolves around the cost/reliability of these improvements relative to the benefits of increased productivity and operator comfort.

Impacts of Alternative Fuels

With the leveling out in petroleum prices, much of the publicity about the movement towards ethanol and vegetable oils as alternative fuels has diminished. Even though there currently are ample fuel supplies, research and development in the areas outlined earlier should continue since the United States is faced with a finite supply of fossil fuels that eventually will be exhausted.

Any massive program to produce ethanol from sugar or grain crops would have major impacts on grain prices, cost of livestock feeding, and cost of grain derived food products. On the other hand, production of by-products of grain alcohol manufacture, such as distillers dried grains, and corn gluten feed and meal increase as a result of ethanol production. A study by Schnittker Associates (1980) indicated that real corn prices would rise by approximately 15 percent if 4 billion gallons of ethanol were produced (U.S. farmers used approximately 4.3 billion of gallons of gasoline in 1979). Ethanol produced from lignocellulosic crops or residues should have significantly less impact on farm commodity prices, upon commercialization of appropriate technologies.

The high price of vegetable oil relative to diesel fuel precludes any significant replacement of diesel fuel, barring significant changes in existing price relationships. Collins, Griffin, and Lacewell (1982) examined the impacts of diverting vegetable oils to use as diesel fuel replacement. Their research indicated that a 10 percent replacement of agriculture diesel fuel by vegetable oils would increase the price of soybean oil by over 33 cents per pound, or more than double its 1984 price level. A five percent diversion would increase soybean oil prices by about 18 cents per pound or 64 percent.

A Battelle-Columbus Division study for U.S. Department of Energy (1981) indicated a diesel fuel substitute potential of 5 billion gallons per year arising from crops grown on new lands, sequential cropping, changes in crop rotation patterns, new oilseed crops, and some diversion of animal fats from export markets. Although there are sufficient agriculture resources in the United States to permit production of approximately 5 billion gallons per year of triglyceride fuels derived from vegetable oils and animal fats, there is considerable doubt concerning the existence of entrepreneurial incentives, national determination, capital, or infrastructure required for such a huge undertaking in the United States, unless there is a "national emergency".

References

(1) "An Engine Sensor Update," Automotive Engineering, Vol. 90, No. 8, August, 1982.

(2) Buckingham, F., "Tomorrow's Tractor Fuel? Diesel," Implement and Tractor, February, 1983.

(3) Collins, G.S., R.C. Griffin and R.D. Lacewell, "National Economic Implications of Substituting Plant Oils for Diesel Fuel," ASAE Transactions, Publication 4-82, 1982, pp 138.

(4) Conrads, John A "The Service Challenge of the Eighties," paper presented at the National Conference on Agricultural Electronics Applications, American Society of Agricultural Engineers, Chicago, IL., December, 1983.

(5) Danek, R.J., D.R. Bottle and D.J. Kotek, "Micro-processor Instrument Cluster," paper presented at the National Conference on Agricultural Electronics Applications, American Society of Agricultural Engineers, Chicago, IL., December, 1983.

(6) Dann, R., "Agricultural Equipment: Cash Squeeze Slow Development," Machine Digest, September 8, 1983, pp 44-51.

(7) Darcey, C.L., W.A. LePori, C.M. Yarbrough and C.R. Engler, "Lubricating Oil Contamination from Plant Oil Fuels," Transactions of the American Society of Agricultural Engineers, November-December, 1983.

(8) Douglas, L.J., (Solar Energy Research Institute), "Perspectives on the SERI Alcohol Fuels program", Proceedings of the 19th Intersociety Energy Conversion Engineering Conference, Advanced Energy Systems--Their Role in the Future, San Francisco, August, 1984, pp. 691, 692.

(9) Dunn, J.R. and K.C. Schneeberger, "Economic Implications for the Potential Development of a Vegetable Oil Fuel Industry, "ASAE Transactions, Publication 4-82, 1982, pp 149-150, 153-155.

(10) "Facing Up To Change" Implement and Tractor, January, 1984, pp 10-20.

(11) Galloway, T.R. and Patterson, J. (Hercules Energy Research Center), "New Opportunities and Challenges in Production of Methanol Fuels", Proceedings of the 19th Intersociety Energy Conversion Engineering Conference, Advanced Energy Systems--Their Role in the Future, San Francisco, August, 1984, pp. 648-650.

(12) Kah, G.F., Whitson, D.F. and Seedorf M.W., "Agricultural Energy management in California: A Utility's Perspective," paper presented at the Winter Meeting of the American Society of Agricultural Engineers, December 13-16, 1983, Chicago, IL.

(13) Keim, Carroll R., "Technology and Economic of Fermentation Alcohol-An Update," Enzyme and Microbial Technology, Vol. 5, March, 1983, pp 103-114.

(14) Kemylama, K., T. Okazaki, H. Hashimoto, et al., Komatsu Ltd (Japan), "Electronically Controlled High Pressure Injection System for Heavy Duty Diesel Engine-Kompics," paper #810997, Society of Automotive Engineers, February, 1981.

(15) Kimberley, J.A. and J.R. Voss, American Bosch Diesel Products Division of UTC, "A Mid-Range Fuel Injection Pump and Its Electronics," paper #820448, Society of Automotive Engineers, February, 1982.

(16) Lipinsky, E.S., T.A. McClure, S. Kresovitch, J.L. Otis, C.K. Wagner, D.A. Trayser and H.R. Appelbaum, Systems Study of Animal Fats and Vegetable Oils for Use as Substitute and Emergency Diesel Fuels, report for the U.S. Dept. of Energy Battelle Columbus Laboratories, Columbus, Ohio, 1981.

(17) Mueller, G.R. and J.T. Knepler, "A Digital Instrumentation System for Agricultural and Construction Equipment," Electronic Design, 1983, pp .

(18) Office of Technology Assessment, Energy from Biological Processes, Washington, D.C.; 1980.

(19) Ordubadi, A., Bolt Beranek and Newman Inc., "Fault Detection in Internal Combustion Engines Using an Acoustic Signal," paper #820365, Society of Automotive Engineers, February, 1982.

(20) "Pilots Talking to Instrument Panels: The Next Phase?" Society of Automotive Engineers, Inc., August 1982, pp 81-83.

(21) Reams, L.A., T.A. Wiemero, M.B. Levin, et al, Ford Motor Company, "Capabilities of Diesel Electronic Fuel Control," paper #820449, Society of Automotive Engineers, February, 1982.

(22) Schnittker Associates, Ethanol: Farm and fuel Issues, contract No. T17622921, submitted to the U.S. National Alcohol Fuels Commission, Washington, D.C., August 1980.

(23) Society of Automotive Engineers "Tractor Dashboard Information system Updated," Automotive Engineering, September, 1982, volume 90, No. 9, pp .

(24) Stout, B.A., Texas A&M University, Department of Agricultural Engineering, College Station, Texas; personal communication, May 30, 1984.

(25) "Top 10 Farm Trends of 1982," Successful Farming, November, 1983, pp 41-46.

(26) U.S. Department of Commerce, Bureau of the Census, 1979 Farm Energy Survey, Volume 5, Special Reports, Part 9.

Background Paper No. 28

Crop Separation, Cleaning, and Processing

Battelle Columbus Laboratories
Columbus, Ohio

November 1985

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Technology, Public Policy, and the Changing Structure of American Agriculture." The views expressed are those of the author(s) and not necessarily those of OTA.

CROP SEPARATION, CLEANING, AND PROCESSING TECHNOLOGIES

Summary

Two major lines of research in crop separation, cleaning, and processing technologies include (1) new methods for separating and cleaning grain, and (2) in-field or on-farm processing of forages and oilseeds.

Grain harvesting productivity has been increased over the past three decades by increasing the size and power of combines without changing the basic principles used to separate or clean the grain. Combines separate grain by beating and rubbing the grain stalk between a stationary surface and a cylinder rotating at high speed. The chaff and other debris are cleaned from the grain by blowing a large amount of air through the grain/chaff mix. The differences in abilities of the two materials to float on the airstream affects their separation.

Sensors and control systems have been developed to provide better information to the operator on the performance of the combine. Information on cylinder RPM, cleaning fan speed, and speed of other combine rotating parts are provided, along with engine monitoring features. Sensors and controls to determine the feeding rate into the separating cylinder, and to modify the ground speed as needed to compensate, are being developed. Mechanical sensors to detect the proximity of the gathering head to the ground are being used, along with grain loss monitors to determine if excessive grain is being lost with the chaff. Due to limitations on increasing the physical size of combines, future combines may use new principles to separate and clean the grain.

On-farm processing of forages and oilseeds provides one way to increase the farm value of these crops by conducting some of the initial processing in the field or on the farm. Some in-field processing of vegetables (e.g., lettuce) is now conducted, with trimming, wrapping, and packaging being done, in the field. Juice extraction from alfalfa and other forages has been considered in order to reduce weather related risks, and dry matter and nutrient losses associated with present forage harvesting practices of ensiling, sun curing, and dehydration.

Alfalfa processing involves two operations; (1) separating juice containing protein from the plant's leaves, and (2) recovery of protein from the juice. The leaf juice protein may be used for human consumption with the remaining residues fed to cattle and converted to meat or dairy products.

On-farm extraction of oil from crops such as soybeans and sunflowers has been studied as a result of the interest in developing vegetable oils as potential substitutes for diesel fuel. For on-farm systems, the mechanical or screw press extraction is the least capital intensive, and the least complicated to operate.

Improvement in combine performance is contingent upon learning more about the basic "inner workings" of a combine in order to better understand and possibly change the principles of operation. There is a general need for advanced control systems and reliable electronics associated with the various types of combine measurements and control mechanisms.

Commercialization of on-farm or small-scale oilseed extraction, and fractionation of forage crops currently is hindered by unfavorable cost/benefit economics. Vegetable oils are approximately double the price of diesel fuel, thus there is no incentive for farmers to substitute vegetable oils for fuel use. On the other hand, the relatively low price for conventional protein sources, such as soybean meal, does not create sufficient incentives for farmers to adopt leaf protein extraction technologies. There also is need to further refine leaf protein recovery and processing procedures to reduce their complexity, costs, and energy requirements.

Farmers have little control over the existing cost/price relationships; therefore adoption of on-farm processing of forages and oilseeds is contingent upon many domestic and international economic/political/institutional factors which currently override technological considerations. On the other hand, most of the technologies required for improved combine performance should be achieved by the end of the decade. These technologies should further increase grain harvesting productivity in terms of acres per hour, while reducing grain losses and minimizing down-time. The costs of these technologies should not significantly add to the total cost of today's combines.

CROP SEPARATION, CLEANING AND PROCESSING TECHNOLOGIES

Introduction

Crop separation, cleaning and processing technologies are those technologies that will be used to increase harvest productivity and improve the quality and value of crops. The major lines of research in this area are:

- New methods for separating and cleaning grain
- In-field or on-farm processing of forages and oilseeds.

Emphasis in this paper is placed on harvesters for grain, oilseed, and forage crops.*

Over 67 percent of United States' grain combines and over 80 percent of the corn heads for combines are located in the 12 states comprising the Corn Belt, Lake States, and Great Plains. Over 66 percent of the field forage harvesters are in the Northeast, Corn Belt, and Lake States, roughly paralleling the major dairy production regions of the country.

Current methods used for grain separation and cleaning originated from grain threshing by the earliest farmers. These methods have worked well for many years and have been mechanized to a very high degree. Harvest productivity has been increased by increasing the size and power of the harvesting machines without changing the basic principles used to separate or clean the crop. Some harvesting machines, especially grain combines, may be reaching limits in physical size because of shipping and over-the-road travel constraints. In order to increase productivity, future harvesting machines may use different basic principles based on new technologies.

---

* Harvesting developments in fruits and vegetables are addressed in a separate paper for OTA on labor saving technologies.

Today's harvesters are complicated machines for farmers to operate and maintain. A large number of internal functions must be monitored and there are multiple adjustments required in response to changing field conditions. In addition, the operator must be aware of any faults that could cause a breakdown of the machine. Because the timing of crop harvest can be so critical, a breakdown of the machine can cost the farmer hundreds of dollars per day.

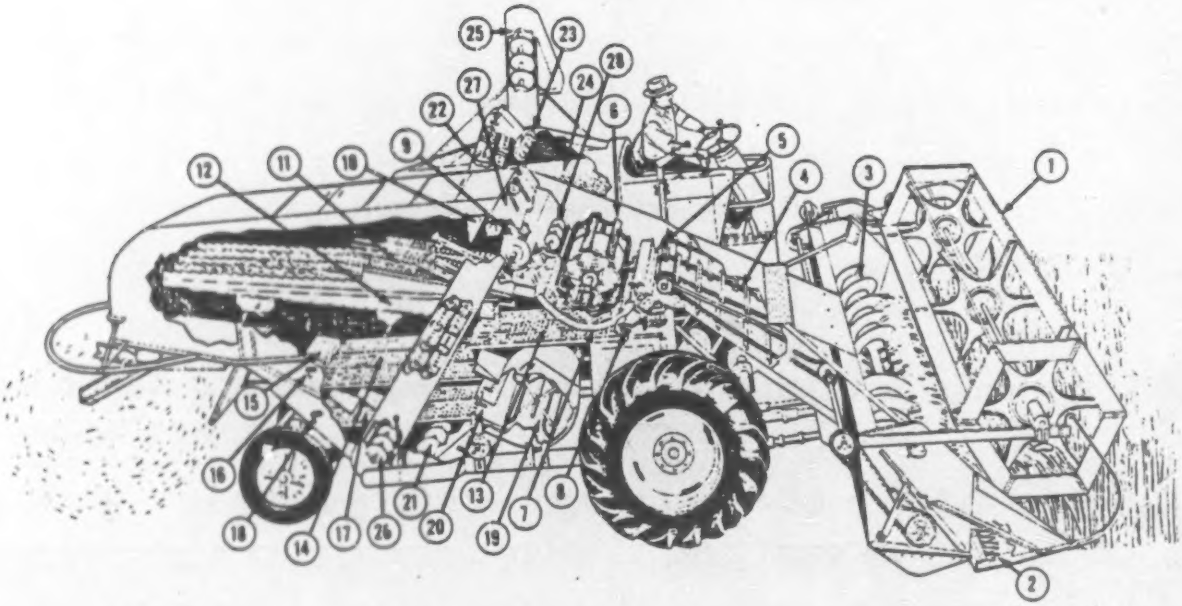
In-field processing refers to a method of harvest where all or part of the initial processing of certain crops is done in the field as the crop is harvested; on-farm processing refers to processing the crop on-the-farm after harvest. One example is on-farm processing and utilization of vegetable oil crops, such as sunflower and soybeans. For some crops, the farmer adds value when processing is done in the field, thus increasing his revenue. In-field processing may also be done to reduce the bulk of a commodity for shipping purposes. Another application for this technology is the extraction of proteins or other useful products from agricultural crops, such as alfalfa, that are not traditionally used for human consumption.

Current State of the Art

The three crops producing the most total farm revenue in the U.S. are corn, soybeans and wheat. These crops represent about half of the total dollar value of U.S. produced field crops. Harvest mechanization of these crops is very advanced. Large, powerful and expensive machines are used for harvest. For most farmers, the combine is the single most expensive piece of equipment on the farm. The average price of a new combine in the United States in 1983 was over $60,000, with some of the largest machines costing $90-100,000. Between 1960 and 1982, the average number of acres harvested per combine, per year, rose from 177 to 380 acres. Today's largest combines harvest 5-7 acres per hour, depending on the crop. The high level of mechanization is a major contributing factor in keeping labor costs under 10 percent of the production value for corn, soybeans, and wheat.

New Methods for Separating and Cleaning Grain

Current machines separate grain by beating and rubbing the grain between a stationary surface and a cylinder rotating at high speed (Figure 1). The chaff and other debris are cleaned from the grain by blowing a large amount of air through the grain chaff mix. The difference in abilities of the two types of material to float on the airstream effects their separation. This "brute-force" system has worked well for over a hundred years. To increase the productivity of these machines, the



1	Reel
2	Cutter bar
3	Header auger
4	Feeder conveyor
5	Feeder beater
6	Cylinder
7	Concaves
8	Concave clearance adjustment
9	Beater
10	Retarder flap
11	Straw walkers
12	Grain returns
13	Grain pan
14	Chaffer
15	Chaffer extension
16	Chaffer adjustment
17	Shoe sieve
18	Shoe sieve adjustment
19	Fan
20	Wind vane adjustment
21	Clean-grain auger
22	Clean-grain elevator
23	Grain leveling auger
24	Grain tank
25	Unloading auger
26	Tailings auger
27	Tailings elevator
28	Tailings distributor auger

FIGURE 1. CUTAWAY VIEW OF A SELF-PROPELLED COMBINE.

Source: D. Hunt, Farm Power and Machinery Management, Iowa State University Press, 8th ed., 1983, pp. 131.

gathering units, separating cylinder, and cleaning sieves can be made larger. This has occured during the last 25 years. Another way to increase productivity is to increase the machine speed through the field. The gathering units remain the same size but the separating cylinder and cleaning sieves must be designed to handle the larger throughputs. The recent introduction of combines using "rotary" type separating units is not a change in the basic principles of separation. This technology does seem to allow larger throughput in the same size harvester. There is an upper limit to the operating speed because these machines are operated by humans. The operator has a large number of tasks that must be performed and increased ground speed further complicates his task load. Farmers have resisted increasing their ground speed because they are uncomfortable with their ability to monitor and control the machine at the higher speeds.

Sensors and control systems are being developed to provide better information to the operator on the performance of the combine. Information on cylinder RPM, cleaning fan speed, and the speed of other rotating parts in the combine are now provided to the operator along with the usual engine monitoring features. Sensors and controls to determine the feeding rate into the separating cylinder, and to modify the ground speed as needed to compensate, are being developed. Mechanical sensors to detect the proximity of the gathering head to the ground have been used for several years. Grain loss monitors are used to determine if excessive grain is being lost with the chaff and straw and to signal the operator that the system must be adjusted.

On-Farm Processing

As farmers are forced to become more efficient, they will attempt to increase their returns for a given amount of land. One way to do this is to increase the farm value of the crop by doing some of the initial processing in the field or on the farm. A good example of this is the extraction of leaf protein juice from alfalfa. Alfalfa is a commodity that cannot be used directly by monogastric animals or humans for food because it cannot be digested. However, if the leaf juice protein is extracted for feeding to swine or poultry or for human consumption, the remaining residue can be be used by cattle and converted to meat or dairy products.

Another example of in-field processing is the trimming, wrapping, and packaging of some fruit and vegetable crops in the field. Some growers perform these operations in the field for fresh market lettuce, broccoli, cauliflower and grapes. The advantage to the processor is that his investment in a packaging plant is reduced and he can eliminate the need for packing union employees. Most of these operations require that the harvest season be long enough that the timeliness of harvest is not affected. Since Midwest weather conditions generally are not satisfactory for this type of system, most of these systems are being developed for use in growing areas with warmer climates, such as California.

Some process fruits and vegetables are transported long distances to processing and packaging plants. An example of this is the harvest of process tomatoes. Processing plants are often over a hundred miles from the harvest site. In the case of tomatoes, a large amount of the water that is transported from the harvest site is removed during processing. If the water could be removed at harvest, considerable savings in transportation could result. The main concern is that quality standards be maintained since the processor would not have the same control over the grower as can be maintained in the process plant. In-field crushing of juice grapes is practiced commercially in France and California. The processor maintains control over the entire operation to ensure that FDA and USDA quality control standards are met.

Forages

Juice extraction from alfalfa and other forages has been considered for a number of years in order to reduce weather risks, and dry matter and nutrient losses associated with present harvesting practives of ensiling, sun curing, and dehydration. Basically, there are two general operations. The first operation separates plant juice containing protein from the insoluble fibrous fraction, while the second recovers protein from the juice (Bray, 1982). The first operation, separation of protein juice from fiber, involves a two-step process. First it is necessary to rupture the plant cells; then, the macerated crop is dewatered by compressing the fiber mat and forcing out the juice.

Research has been conducted on the relative performance of several different press configurations, such as the screw press, perforated roller press, internal roller press, cone press, etc. (Gu, et al., 1982). Kline, (1980) patented a self-propelled alfalfa field processor to separate fiber and protein components and a de-proteinized liquid component which is reapplied to the field as the vehicle advances. The apparatus includes a harvesting head assembly which is mounted on the front of the vehicle to cut the alfalfa and as a means to convey the alfalfa to a mascerator which shreds the harvested alfalfa. The mascerated alfalfa is separated into fibrous and liquid fractions by a dewatering press which is connected to the mascerator by conveyor. The fibrous fraction is blown into a trailer pulled behind the vehicle. The liquid fraction is heated to a predetermined temperature and is pumped into a holding tank where the protein in the liquid coagulates and floats on the deproteinized liquid. Protein is skimmed from the deproteinized liquid and is collected in a storage container mounted on the vehicle. The deproteinized liquid is sprayed on the ground behind the vehicle. The concept is illustrated in Figure 2.

Generally, the incentive for leaf protein fractionation is that a weather independent system can be devised in which processing occurs on the farm and at least one of the products is used at the production site. The ideal situation might be a combined dairy and hog production farm using all of the products growing on site, thus reducing transportation expenses, storage costs, and spoilage (Office of Technology Assessment, 1983).

Researchers at the University of Wisconsin also have developed machinery to obtain a pressed forage, which can be preserved directly as silage. The pressed forage has a moisture content of 65 percent (compared to approximately 80 percent for fresh cut alfalfa), which is a desirable moisture concentration for proper fermentation in the silo. Field losses can be reduced to about 2 percent compared with 32 percent or higher when the crop is preserved as baled hay. The pressed residues contain 50-80 percent of the original green crop's dry matter, and about 70-80 percent of the original protein content, which is considerably higher than that of sun-dried hays.

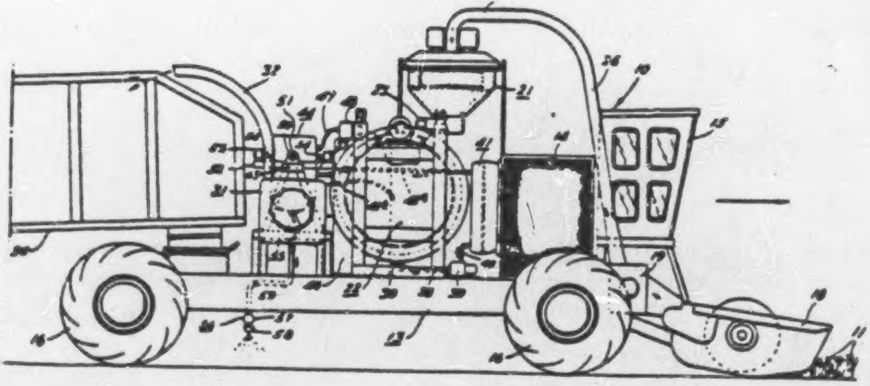


FIGURE 2. SELF PROPELLED DEWATERING PRESS FOR ALFALFA

Source: Donald C. Kline, United States Patent No. 4,207,811 assigned to Lehampton Farms, Inc.; Macurgie, PA.; June 17, 1980.

Prototype equipment for green plant masceration and juice expression are relatively well developed for on-farm systems. Not as well defined are systems for processing the plant juice and subsequent protein separation. Centralized plant systems that have been investigated include use of commercial decanter centrifuges for single and multi-fractionation separating, the use of ultrafiltration, and multistep processes including both centrifuging and ultrafiltration. However the cost and/or complexity of these systems are not compatible with farm scale operations. Wisconsin researchers have examined less expensive and less complex separation systems which might be used to separate heat precipitated plant use protein. These include the use of a low cost centrifuge, use of a flotation system, and use of a belt filtration systems (Straub, et al, 1979).

On-Farm Oilseed Processing

Interest in potential substitution of vegetable oils for diesel fuel has led to research on-farm means for extracting oil from crops such as soybeans and sunflower. Currently all commercial oilseed extraction is done in large centralized plants with average capacities exceeding 100 million pounds of vegetable oil annually.

There are three basic methods of oilseed extraction. These include (1) mechanical or full-press extraction; (2) direct solvent extraction, (3) pre-press solvent extraction. In the latter two extraction methods, solvent is used to separate the oil from the seed. Then, the solvent is distilled to recover the vegetable oil. These methods require large capital investments and distillation equipment and also require handling of highly volatile substances. Therefore, such solvent extraction systems are not appropriate for small scale on-farm operations.

For on-farm systems, the mechanical or screw press extraction is least capital intensive, and also least complicated to operate. A number of such small scale extraction systems have been tested, which basically involve a continuous process with a screw press consisting of a worm shaft rotating within a pressing cylinder or cage, which squeezes the oil from the seed. Oil extraction is facilitated by heating the oilseeds prior to mechanical pressing.

Other Crop Separation or Processing Technologies

Kranzler, (1983) reported potential agricultural operations involving image processing. With this technology an image formed by a television camera or solid state sensor array is digitized to form a matrix of individual picture elements which are held in a computer's memory for manipulation and intrepretation. Sorting, grading, and inspection of raw and processed food products are potential applications of this technology. Some potential examples, some of which are already in operation, include:

- Sorting cucumbers into three grades according to shape, and five sizes according to length. This is being done at a rate of up to 10 per second, with the results being tallied and displayed for individual growers and printed on a hard copy.

- Detection of surface cuts, blemishes, and bruises on fresh market fruits and vegetables.

- Inspection of pizzas for crust deformation and distribution of toppings.

- Assistance with meat grading and automation of trimming. One system under development detects fat and marbling and reports it as a percentage of total meat weight. The computer vision system calculated the location of major fat sections on the image, and transmits the exact location to a robot controlled water jet trimmer. A similar system is being designed to separate the white meat from the blood meat and bone in a tuna cannery.

Major Breakthroughs Needed

Grain Combines

Generally speaking, more basic information is required on the "inner workings" of a combine in order to better understand and possibly change the basic principles of operation. There is a limitation on further increases to the physical size of the combine due to shipping and over-the-road transportation constraints. There is also an upper limit to harvesting speed due to reduced control over the machine at higher speeds. In recent years there has been increased concern about grain quality, especially the effects of high speed combine components on seed coat cracking and breaking. These effects, while not critical, indicate a need to develop new basic principles to separate and clean high quality grain crops.

A general need exists for more work on new control systems and more reliable and accurate electronics associated with the various types of combine measurements and control mechanisms.

Specifically, some needs include:

- Improved sensors to control the feed rate of material into a combine. The successful measurement of feed rate provides useful information to help optimize combine performance; the information can be provided to the operator for manual control or to an automatic controller.

- More accurate and reliable mobile grain moisture transducers. Such sensors would allow for compensation of forward speeds and harvester adjustments. Also, the sensors might indicate whether harvesting should even be continued if harvesting conditions were too moist or too dry. Existing sensors exhibit poor moisture sensitivity, especially at lower moisture contents. Sensors tested at Purdue University from 1979 through 1981 were far superior in detecting corn grain moisture than wheat or soybean moisture. The moisture content of crops varies constantly from variety-to-variety, from one part of the field to another, and with changes in sunlight, humidity, and wind conditions throughout the day.

- As with all electronic equipment for use in agriculture, there are concerns regarding component reliability and servicability. Environmental conditions in agriculture undergo extremes of temperature, humidity, dust, vibration, and electrical transients.

In-Field/On-Farm Processing

A major constraint to adoption of in-field or on farm-processing technologies for oilseed extraction or fractionation of green forage crops is unfavorable economics. On the one hand, the low price for oilseed meal of $190-200 per ton inhibits farmers from adopting less proven and more expensive leaf protein extraction technologies. Adoption is further complicated by the need for further refinement of the protein recovery and processing procedures in order to reduce their complexity, cost, and energy requirements. Generally, farmers are not used to thinking in terms of on-farm processing and the associated technology required.

While relatively low oilseed meal prices retard commercial adoption of forage crop fractionation, the high cost of extracting vegetable oil from oilseeds with on-farm processing systems retards its adoption. The cost per gallon of vegetable oil derived from small on-farm presses has been estimated to range from $1.80 to $2.60 per gallon. Even if the vegetable oil could be used "as extracted" in diesel tractors, it is not economically viable with diesel fuel costs approximating $1 per gallon in 1984.

From a technical standpoint, there is a need for further refining of on-farm extracted vegetable oil to render it effective for use in diesel engines. There is need to evaluate the various oil purity levels that are associated with small scale oilseed processing and conversion to establish which oils are acceptable, and at which level of purity. Processing systems must be developed to achieve the desired purity levels at reasonable costs.

Other problems to be addressed with on-farm vegetable oil extraction include (1) blockage of materials in the presses, (2) excessive fine materials and seed particles in the oil, (3) excessive oil remaining in the press, (4) adequate means of storing the extracted oil and residual press cake, and (5) effects of feeding the press cake to livestock. The last problem includes the effect of processing parameters, such as temperature, on animal growth or toxin levels in the oilseed residue.

Likely Timing of Commercial Introduction

Most of the breakthroughs required for improved combine performance should be achieved by the end of the decade. All of the major combine manufacturers, along with agricultural engineers at a number of universities, are concentrating on developing the electronic componentry required to successfully develop automatic guidance, automatic speed control, automatic control of header height, and instantaneous measurement of harvesting performance. Further speeding adoption will be the ability to provide reliable and serviceable components. The fact that all major manufacturers are aware of these requirements should be a factor enhancing successful development and commercialization.

It is more difficult to predict when on-farm or in-field processing technology will be commercialized. As long as the cost/price ratio for on-farm produced vegetable leaf protein or vegetable oil is unfavorable, as is currently the case, there is little incentive to adopt this technology. A multitude of factors affect these cost/price relationships, some of which have nothing to do with agriculture. Currently, a relatively stable level of United States crude oil imports, coupled with fuel conservation practices and increased domestic oil production, have reduced the urgency of developing vegetable oils as diesel oil substitutes. World soybean supplies are at adequate levels to provide ample supplies of soybean meal, thus making its price more than competitive with leaf protein. Increasing concern for soil erosion may lead to higher production of forages, which could help stimulate on-farm forage fractionation processes.

Institutional Arrangements

Most agricultural engineering departments at land grant universities located in the major grain producing states conduct some research on combines, cotton, and forage harvesters. Some examples include the University of Georgia, (automatic feedback controls for transplant harvesters) Oklahoma State University (electronics related to handling and processing of agricultural materials), Purdue University (crop moisture measurement, feed rate sensors, and computer controlled combine speed), Clemson University (crop moisture measurement), Michigan State University (various aspects of fruit and vegetable mechanization), and Texas A&M University (combine forward speed control).

Cotton harvesting research is conducted at universities such as Texas A&M, Mississippi State University, and at the US Department of Agriculture's southwestern cotton ginning research laboratory in Mesilla Park, New Mexico.

Private industry companies such as Deere and Co., International Harvester, Massey-Ferguson, TRW Inc. and Dickey John also devote extensive resources to developing state-of-the-art technologies for combines.

Considerable research in the United States on leaf protein fractionation has been conducted at the US Department of Agriculture's Western Regional Research Center in Albany, California, and at the University of Wisconsin. The Western Regional Research Center developed the Pro-Xan process to recover protein at a centralized processing plant, from mascerated and pressed alfalfa (Figure 3). The University of Wisconsin has conducted research for a number of years on on-farm systems

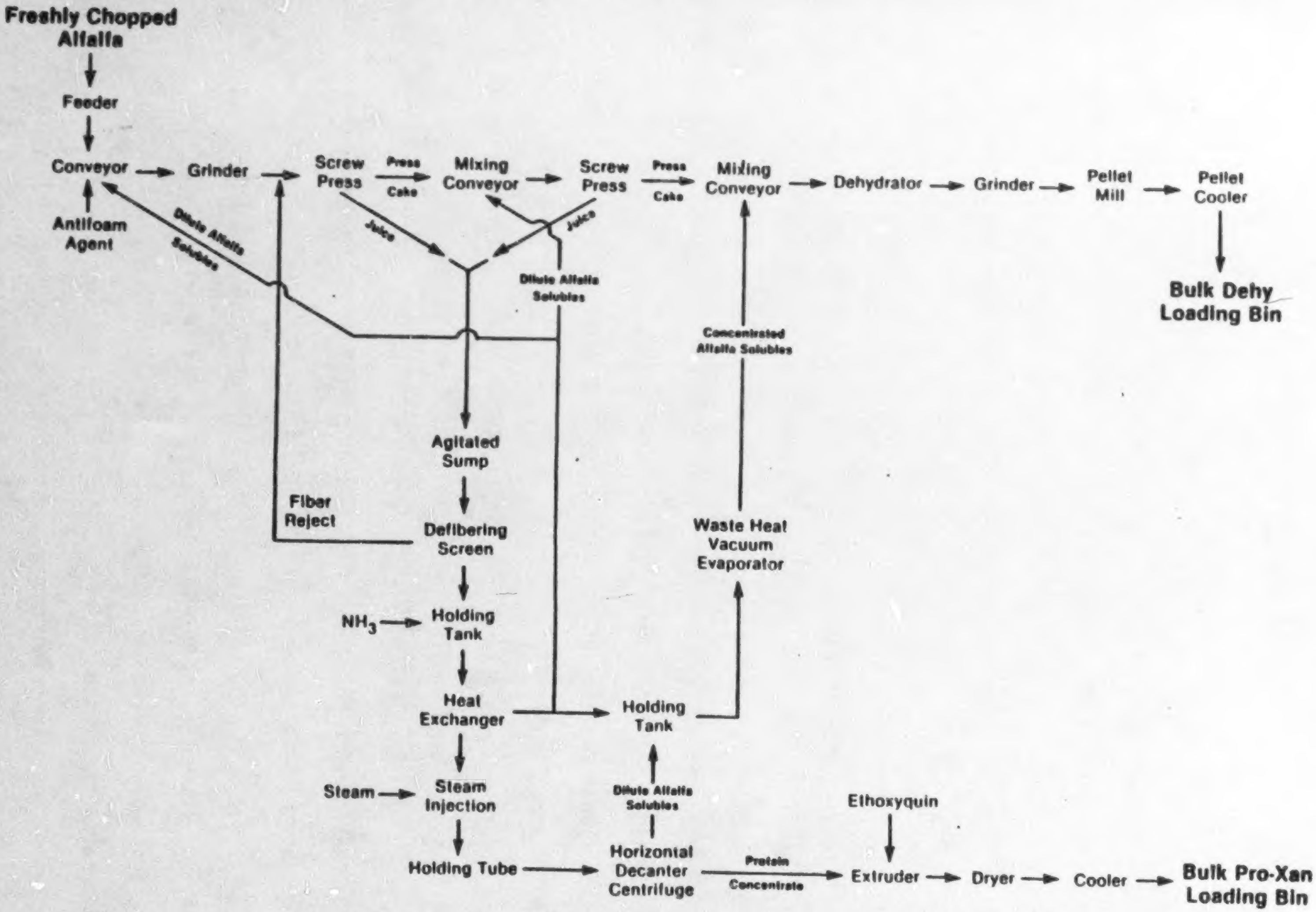

Freshly Chopped Alfalfa
Feeder
Conveyor
Antifoam Agent
Grinder
Screw Press
Press Cake
Mixing Conveyor
Screw Press
Press Cake
Mixing Conveyor
Dehydrator
Grinder
Pellet Mill
Pellet Cooler
Bulk Dehy Loading Bin
Juice
Juice
Dilute Alfalfa Solubles
Dilute Alfalfa Solubles
Concentrated Alfalfa Solubles
Agitated Sump
Fiber Reject
Defibering Screen
NH3
Holding Tank
Heat Exchanger
Holding Tank
Waste Heat Vacuum Evaporator
Steam
Steam Injection
Dilute Alfalfa Solubles
Ethoxyquin
Holding Tube
Horizontal Decanter Centrifuge
Protein Concentrate
Extruder
Dryer
Cooler
Bulk Pro-Xan Loading Bin

FIGURE 3. PRODUCTION OF PRO-XAN FROM ALFALFA

Source: R. V. Enochian, et al.; Producing Pro-Xan (Leaf Protein Concentrate) from Alfalfa: Economics of an Emerging Technology; U. S. Dept. of Agriculture; Agricultural Economic Report No. 445; January, 1980.

for plant juice protein separation and recovery. A number of private companies also have investigated new forage harvesting methods.

On-farm processing of vegetable oil crops has been investigated primarily by universities and private research laboratories. Universities that have been active in this field include the University of Idaho, North Dakota State University, The University of Maryland, and the University of Missouri. The U.S. Department of Agriculture's Northern Regional Research Laboratories in Dekalb, Illinois has also conducted vegetable oil/fuel research. Some private companies that have developed oilseed presses include P.O.S. Pilot Plant Corporation, Anderson International Corporation, Simon-Rosedowns Limited (England), and French Oil Mill Machinery Company.

Potential Primary Impacts

Combine Technologies

The primary impacts of new combine technologies such as automatic guidance, automatic control of ground speed, header height adjustment, grain monitors, etc. is to improve harvesting productivity (acres per hour), reduce grain losses from threshing, and minimize down-time. These new technologies are expected to add less than three percent to existing combine prices (Jones, 1983), or $2,000-3,000 per machine. If a farmer operates the combine over 400 acres per year, and assuming a machine life of ten-years, the additional cost will be less than $1 per acre. This amounts to less than 0.5 percent of the value per acre of most grain crops.

The introduction of automatic control systems reduces routine decisions and adjustments that must be made by the operator on a manual and repetitive basis. Thus, operator fatigue should be reduced. Also, daily production results and servicing requirements will be printed out on the combine's on-board computer, allowing the operator to keep the machine in top operating condition. Keeping the combine in top operating condition should contribute to better harvesting efficiency and a prolonged useful life.

Maximum output will be required from these complex and expensive combines. It is important to minimize lost time in the field due to turning at row ends, unloading grains, cleaning the combine, breakdowns, lubricating, etc., to create high field efficiencies. For example, a combine harvesting soybeans may have a theoretical field capacity of 6.0 acres per hour, or 48 acres in 8 hours. Under normal operations, the farmer may operate at about 75 percent field efficiency with proper management and no breakdowns, or 4.5 acres per hour and 36 acres in 8 hours. If one hour per day is lost due to unplanned stops for minor repairs, the field capacity would be reduced to 31.5 acres per day. At today's custom rates of $25 per acre, the 4.5 acres of production lost would cost the equivalent of $113 per day.

Harvesting timeliness refers to the fact that crop yields are reduced for every day's delay following the most favorable time periods for operation. The timeliness factor is much more important for some crops than others. For example, every day's delay in harvesting soybeans past their optimum harvesting state can reduce yield by 1 percent per day. Corn, on the other hand, only has a harvesting loss of 0.2 percent per day.

If the technologies previously discussed can improve harvesting rates, it could be particularly important for soybean farmers. For example, if harvesting a 100 acre field of soybeans is delayed five days after the optimum period, the grower would lose the equivalent of 5 acres of soybeans. Assuming a soybean yield of 35 bushels per acre and a price of $7 per bushel, the farmer would lose $1,225 or $245 per day.

Finally, simply by reducing grain losses, the farmer could increase net profits from improved combine performance. The average losses in combining corn are 6-7 bushels per acre, while for soybeans, losses are 2-2.5 bushels per acre. An improvement in corn combine performance of 25 percent would reduce grain losses by 1.5-1.75 bushels per acre. At corn prices of $3.00 per bushel, the farmer would save $4.50-$5.25 per acre.

Impacts of In-Field or On-Farm Processing

Bray (1976) indicated two general options for farmers considering leaf protein production, or the more general term, grain crop fractionation. Under the one option the farmer fractionates his fresh forage and uses all of the fractions himself. The dewatered fiber could be fed to cattle either directly or after ensiling. The whole juice could be fed to swine; alternatively the protein could be coagulated and fed to swine, poultry, or calves. If the protein was coagulated, the residual liquor would be applied on the land for its fertilizer value.

Under the second alternative, the farmer would utilize the fiber fractions himself, but would sell either the whole juice or the moist protein curd. Centralized factories would collect juice from farmers from within a convenient radius of the plant for further processing.

Potential benefits of green crop fractionation, whether it is conducted in the fields, on the farm, or at a centralized processing plant include the following:

- Ability to harvest alfalfa and other forages in wet weather, thereby increasing their potential as a cash crop. Increased production of forages would also be beneficial in terms of reducing soil erosion.

- Increased feed value of alfalfa and other green plants.

- Reduced energy requirements compared to current dehydration processes used to produce alfalfa meal and pellets

- The leaf protein concentrate could be feed to monogastric animals, such as swine, whereas forage can be fed only to ruminants.

- Further purification of the leaf protein concentrate would produce a product for human consumption; this may be especially applicable to lesser developed countries which can better produce forages than grain crops.

- Reduced dependence upon oilseed meal for protein.

- The processes are applicable to a wide variety of green lush forages such as oats, bluegrass, sweet corn stalk residues, potatoe vines, and birdsfoot trefoil.

On-farm extraction of vegetable oil from crops such as soybeans, peanuts, and sunflower is technically feasible today. However, as previously indicated, existing cost/benefit economies do not favor its commercialization. If small-scale oilseed processing technology could be perfected and be made cost effective, it would have tremendous impacts on farming, as well as the structure of the existing oilseed processing industry. On-farm storage systems for oil and meal would have to be developed. Farmers would have sizeable capital investment ($30-40,000) for the processing facilities, depending upon the desired equipment capacity. A distribution network would have to be set up to transport vegetable oil from farms to secondary processing facilities for further refining into food grade material. The price structure for oilseeds could be altered significantly relative to other grain crops such as wheat and corn, thus causing a shift from one crop to another before an equilibrium point is reached.

The above scenario for on-farm processing of vegetable oils is not likely to occur in the foreseeable future unless another energy crisis occurs to threaten the availability of diesel fuel necessary to maintain U.S. agricultural productivity.

References

(1) Bray, W.J., "Green-crop fractionation" New Scientist, April 8, 1976, pp 66-68.

(2) Bray, W.J., "Leaf Protein Concentrate: Improved Green Crop Fractionation By Use of Aqueous Extraction", paper no. 82-1536 presented at the Winter Meeting of the American Society of Agricultural Engineers, December 14-17, 1982.

(3) Bruhn, H.D., and R.G. Koegel, "More Usable Protein Per Acre By A Modified Forage Program", Transactions of the ASAE, Vol. 20, No. 4, pp 653-656.

(4) Edwards, R.H., R.E. Miller, and G.O. Kohler, "Commercial Scale Production of Alfalfa Leaf Protein Concentrate", paper no. 81-1524 presented at the Winter Meeting of the American Society of Agricultural Engineers, December 15-18, 1981.

(5) Enochian, R.U., G.O. Kohler, R.H. Edwards, "Producing Pro-Xan (Leaf Protein Concentrate from Alfalfa), United States Department of Agriculture, Agricultural Economic Report No. 445, Washington, D.C., January 1980.

(6) Farsaie, A., B.V. Lessley, J.V. Debarthe, et al, "On-Farm Processing and Utilization of Vegetable Oil Crops", paper no. 83-3556 presented at the Winter Meeting of the American Society of Agricultural Engineers, December 13-16, 1983.

(7) Helgeson, D.L., and L.W. Schaffner, "Economics of On-Farm Sunflower Processing", ASAE Publication 4-82, 1982, pp 173, 187.

(8) Jones, D. "Self Adjusting Combine May Be More Productive", Crops and Soils, American Society of Agronomy, December, 1983.

(9) Kline, D.C., U.S. Patent No. 4,207,811 assigned to Lehampton Farms, Inc. Macurgie, Pennsylvania, June 17, 1980.

(10) Kranzler, G.A., "Impact of Electronics on Materials Handling and Processing", paper no. 1518 of the Oklahoma Agricultural Experiment Station, 1983.

(11) Kruse, J., G.W. Krutz, and L.F. Huggins, "Microprocessor Based Combine Ground Speed Controller", paper #82-3040 presented at the Summer Meeting of the American Society of Agricultural Engineers, June 27-30, 1982.

(12) Lipinsky, E.S., S. Kresovich, C.K. Wagner, et al, "Vegetable Oils and Animal Fats for Diesel Fuels: A Systems Study", ASAE Publication 4-82, 1982, pp 1-10.

(13) Lu-Ping, Gu, Straub, R.J., and R.G. Koegel, "Juice Expression From Deep-Mat Macerated Alfalfa", paper no. 82-1535 presented at the Winter Meeting of the American Society of Agricultural Engineers, December 14-17, 1982.

(14) Mailander, M.P., J.K. Schueller, G.W. Krutz, "An Evaluation of Four Continuous Moisture Sensors on a Combine", paper no. 82-1576 presented at the Winter Meeting of the American Society of Agricultural Engineers, December 14-17, 1982.

(15) Peterson, C.L., D.L. Auld, J.C. Thompson, "Experiments with Vegetable Oil Expression", Transactions of the ASAE, 1983, pp 1298-1302.

(16) Qualls, David E., and G.E. Miles, "Crop Moisture Measurements for Combines". Proceedings of the National Conference on Agricultural Electronics Applications, ASAE, 1983.

(17) Schueller, J., M.P. Mailander, G.W. Krutz, "Combine Feedrate Sensors" paper no. 82-1577, presented at the Winter Meeting of the American Society of Agriculturla Engineers, December 14-17, 1982.

(18) Schueller, J.K., M.P. Mailander, and G.W. Krutz, "Computer Control of Combine Forward Speed and Rotor Speed". Proceedings of the National Conference on Agricultural Electronics Applications, ASAE, 1983.

(19) Straub, R.J., G.P. Barrington, and H.D. Bruhn, "Chemical Preservation of Alfalfa Juice Protein", paper no. 82-1539 presented at the Winter Meeting of the American Society of Agricultural Engineers, December 14-17, 1982.

(20) Straub, R.J., "New Alfalfa Process Yields Protein Rich Concentrate", Feedstuffs, October 5, 1981, p 18.

(21) Straub, R.J., H.D. Bruhn, and G.P. Barrington, "Plant Juice Protein Separation and Recovery", paper no. 79-6531, presented at the Winter Meeting of the American Society of Agricultural Engineers, December 11-14, 1979.

(22) U.S. Congress, Office of Technology Assessment, Plants--The Potentials for Extracting Protein, Medicines, and Other Useful Chemicals, 1983, pp 96-103.